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REMEDIATION VS. PREVENTION OF PCB CONTAMINATION:

A COMPARISON BASED ON RISK AND COST ANALYSIS

by Thomas A. Kwiat

A Non-thesis paper sumbmitted in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering

University of Washington

Department of Civil Engineering

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APPROVAL

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ABSTRACT

The concern over the potential threats posed by improper disposal of hazardous wastes has increased considerably in the past 10 to 15 years. Recent hazardous waste legislation requires actions that substantially increase the costs of waste disposal. As such, waste generators face the choice of conforming to the regulations or disposing the wastes in an initially less expensive, improper manner. Although the former choice may have relatively higher initial costs, the latter may lead to even greater economic burdens on the waste generator. If improper disposal increases threats of harm to human health and/or environment (whether those threats are actual and/or perceived), the responsible party may face costs of remedial actions, fines, and litigation. Even though those costs may not become manifest until several years into the future, those costs are likely to outweigh those for proper disposal.

A hypothetical case study using polychlorinated biphenyls (PCBs) as the waste stream of interest is used to examine this hypothesis. The literature review preceding the case study discusses PCBs and their potential threat to human and ecological endpoints, present hazardous waste management practices with emphasis on PCBs, and the use of risk assessments in remedial activities. For both risk assessments of human health and ecological damage, emphasis is placed on their limitations and deficiencies.

The results indicate that proper disposal is by far more cost effective than improper disposal. Under the latter scenario, the following alternative actions are considered, in order of increasing costs: Moderate remediation (cleanup to 10 ppm PCB soil), Extensive remediation (cleanup to 1 ppm PCB soil), and No Cleanup, whose cost is driven by the potential for litigation costs due to increased risks of cancer incidence amongst the population exposed.

INTRODUCTION

The costs of properly handling and disposing a given hazardous waste stream may appear to be rather exorbitant from the perspective of a waste generator. However, if the applicable regulations and requirements are not followed completely, albeit intentionally or due to negligence, the generator may end up bearing an even greater financial burden, due to costs of remedial action, litigation, etc. This paper synthesizes existing literature in an attempt to illustrate the hypothesis that the "legal" approach (i.e. proper disposal) can be more cost effective. For the purposes of this report, the author has developed a quasi-hypothetical but realistic situation based on a waste stream consisting of polychlorinated biphenyls (PCBs) to demonstrate this hypothesis.

As indicated above, the total costs to the waste generator may exceed those required for disposal only. If the party is responsible for creating an "illegal" site or a spill, say, it may undergo litigation initiated by the Environmental Protection Agency (EPA) in an attempt to recover costs for the remedial activities (if EPA conducted those activities). In addition, section 107(a) of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) contains provisions for state governments, private citizens or action groups to sue for any or all damages or perceived damages that may or may not have occurred (*Findley & Farber, 1988*). Such damages may be based on a risk assessment, with respect to human health or ecological endpoints, that would factor in determining if the generator should be held liable.

This paper consists of a detailed review of existing literature on PCBs, hazardous wastes in general, and risk assessment methodologies, highlighting key information applicable to the hypothetical case. I intend this paper, primarily via the hypothetical case study, to support the following notions:

- (1) A given generator is for the most part better off by following the regulations and bearing the relatively high initial costs of proper disposal
- (2) Perception of risk may significantly influence the potential litigation costs
- (3) Human health risk assessments play an important role in determining adequate cleanup levels for hazardous waste sites

LITERATURE REVIEW

Scope This background discussion is intended to provide an understanding of the factors and issues that entail the forthcoming case study. Overall, many studies have been conducted to determine the chemical properties and health effects of PCBs. The properties are well established, but the health effects remain open to debate, in particular PCBs' potential for carcinogenicity. Despite the uncertainties, regulations and standards have been established to control the threat PCBs pose. Elements of the Toxic Substances Control Act, the Comprehensive Environmental Response, Compensation and Liability Act, and the Resource Conservation and Recovery Act may influence the situation at hand. Cleanup standards may be based on EPA's drinking water standards, ambient water and air criteria, the FDA's limits on PCB concentrations in fish and other food products, and some state regulations. Risk assessments have been conducted on sites contaminated with PCBs; many of the typical pitfalls associated with present-day risk assessment approaches are evident in situations where PCBs are the primary chemical of concern.

This section provides background on the most important aspects of these three areas: PCBs, hazardous waste management (in particular those regulations which apply to PCBs), and risk assessment practices. Following this literature review is a hypothetical case study which applies and examines much of what is discussed below.

Polychlorinated Biphenyls (PCBs)

This class of organic compounds has received a great deal of attention over the past twenty years. "PCBs" is a catch-all term for a group of 209 congeners, each consisting of a biphenyl ring and a combination of anywhere from one up to twelve chlorine atoms (*Metcalfe, 1986*). Aroclor 1248, 1254 and 1260 are example trade names of PCBs commonly found in the environment. Despite the variances in their properties and behavior in the environment, PCBs are typically addressed within legal and management contexts as though they are in effect one compound. The primary properties of concern are persistence and the ability to bioaccumulate in aquatic organisms (*Norstrom, 1986*). These properties, coupled with past practices, result in widespread distribution of PCBs throughout the environment (air, water, soils, biota); this dissemination enhances the belief that PCBs pose potentially significant harm to human health as well as the environment itself (e.g. liver toxicity in rainbow trout) (*Norstrom, 1986*). Federal regulations and limits on PCB allowable levels and uses have helped to reduce levels found in biota and human tissues; but significant levels of PCB contamination remain (*US EPA, 1980*).

Sources and Pathways Due to desirable characteristics such as insulating capacity and non-flammability, PCBs have been used in a variety of contexts, especially in electrical equipment as coolants and lubricants, but also in such items as carbon paper, plastics, adhesives, paints, etc. (*Belongia et al, 1985*) Manufactured exclusively by Monsanto in the United States and taking on a variety of trade names (e.g. Aroclor), PCBs were produced from 1929 until 1977, constituting a total output of approximately 1.2 billion pounds (*Belongia et al, 1985*). When concern over potential health effects became manifest (in particular due to the "Yusho" incident in Japan), Monsanto voluntarily stopped production (*Belongia et al, 1985*). Later, usage was banned

except for <u>"closed" systems</u> (such as transformers - *Norstrom, 1986*).

Despite the ban on direct production, a significant amount of PCBs can be found throughout the environment (*Norstrom, 1986*). In addition, they are by-products from the formation of various other chemicals (*US EPA, 1983*). The EPA has estimated that 10^8 kg of PCB are dispersed throughout the world, with 1/3 of total production still in use, and another 1/3 in landfills or storage (*Norstrom, 1986*). *Tateya et al (1988)* estimated that 2/3 of total production is still in use, primarily in old transformers. Although it is difficult to accurately determine the exact fate of the total production of PCBs, it is apparent that widespread contamination has occurred, and due to PCBs' persistence, will exist in the environment for the foreseeable future.

In the past, PCBs were routinely disposed of under permit through industrial discharges into rivers and streams, as well as in open landfills (*Belongia et al, 1985*). Although legal at the time, these practices have served as the principal causes for the now existing hazards. PCBs in transformers and capacitors also pose a threat, although the dangers are limited mainly to fires and leaks or spills. The potential effects are enhanced in a fire situation, because the combustion of PCBs typically creates polychlorinated-dibenzofurans (PCDFs) and dioxins, both of which have been found to be far more toxic than PCBs themselves (*Carrier, 1986*). Several prominent incidents have occurred within the last ten years; the fires in the Binghamton, NY state office building and the San Francisco Pacific Gas Co. building are perhaps the most well known (*Carrier, 1986*). In the former case, over 40 million dollars have been spent to clean up the PCB, PCDF, and dioxin residues, yet the building remains unoccupied.

<u>Effects on Humans</u> A great variety of health effects have been attributed to PCB exposure. <u>Acute effects</u> are believed to include liver damage, chloracne, etc. (*Safe, 1986*) Table 1 summarizes the prominent effects reported due to occupational

TABLE 1. Effects of Occupational Exposures to Polychlorinated Biphenyls

Folliculitis and acneform dermatoses
Skin neoplasia (uncertain)
Acute hepatocellular injury (hepatitis)
Subacute hepatic necrosis with possible cirrhosis
Male infertility
Female infertility (suspected)
Embryotoxicity
Teratogenesis
Spontaneous abortion/fetal death
Neonatal death (suspected)
Low birth weight
Developmental disabilities (suspected)
Immune suppression (suspected)

Source: Grisham, 1986.

exposures (note: corresponding exposure levels were not reported). As alluded to earlier, the most infamous case of apparent PCB poisoning occurred in Japan in 1968. Called the "Yusho Syndrome," over 1000 people became ill after ingesting rice that was cooked using an oil contaminated with 2000 to 3000 ppm Kanechlor 400, a Japanese trade name for PCBs (*Wilson, 1987 and US EPA, 1980*). It was estimated that affected individuals <u>ingested an average of two grams of PCBs</u> (*US EPA, 1980*). Patients experienced skin discoloration, chloracne, mild jaundice, vomiting, diarrhea, and respiratory problems. Symptoms were exhibited also by new-born babies, especially those that were breast-fed (*Waldbott, 1978*). These effects were initially linked to PCBs, but are now attributed to PCDFs, which were found to be in the rice oil at concentrations ranging from 1.6 to 5 ppm (*Cordle et al, 1985 and US EPA, 1980*). So even though PCBs in and of themselves may not be as toxic as originally believed, if PCDFs and/or dioxins are also present, then the concern over potential adverse effects remains justified, perhaps even magnified. Moreover, "...the bioaccumulation of these compounds may render the individual more susceptible to injury from subsequent exposure to other exogenous chemicals" (*Grisham, 1986*).

In spite of the publicity over PCBs' threat to human health, exposure to PCBs in the U.S. has never been as acute as the Japan incident (*Belongia et al, 1985*). However, the primary concern these days lies in the <u>potential for chronic toxicity</u> (*US EPA, 1977*). Due to their lipophilic nature, PCBs have been shown to accumulate in human adipose tissue, as well as in blood serum (although no firm link has been established between these elevated levels and chronic effects - *Belongia et al, 1985 and Stehr-Green et al, 1986a*). Average concentrations of PCBs in human adipose tissue have been estimated at 1 ppm (*US EPA, 1980*). Table 2 summarizes the results of one study depicting the levels in human specimens. This accumulation tends to remain for a long time, since the body has <u>difficulty metabolizing PCBs</u>, especially

TABLE 2. Levels of Polychlorinated Biphenyls in Human Adipose Tissue

Data Source	Sample Size	Percent Nondetected	Percent 1 ppm	Percent 1-2 ppm	Percent 2 ppm
Yobs,1972	688	34.2	33.3	27.3	5.2
FY 1973 Survey	1277	24.5	40.2	29.6	5.5
FY 1974	1047	9.1	50.6	35.4	4.9

Source: US EPA, 1980.

those with relatively high chlorine content (*Carrier, 1986*). The concern is supported by animal bioassays which indicate that these compounds may be carcinogenic, teratogenic, and/or fetotoxic (*US EPA, 1984*). A large number of studies have been conducted over the years; the overall results of the bioassays have been inconclusive, but suggestive of adverse effects (Tables 3 and 4 summarize the results of these studies conducted on mice and rats, respectively.) In addition, epidemiological studies have yet to establish that PCBs result in a significant increase in the incidence of human cancer (*Cordle et al, 1985*). Nevertheless, the EPA has classified PCBs as a class B2 - probable human carcinogen (*US EPA, 1984*).

Effects on Ecosystems PCBs are known to bioaccumulate and bioconcentrate in the food chain, primarily in aquatic organisms (*US EPA, 1984*). Bioconcentration factors (BCFs) vary greatly among species; for instance, the BCF has been estimated to be 3000 for brook trout and 274,000 for the fathead minnow (*US EPA, 1974*). For freshwater fish and shellfish, the EPA has estimated an average BCF of 31,200 (*US EPA, 1980*).

Fish and benthic organisms have been examined and found to have fairly high concentrations of PCBs in their fatty tissues. In North Atlantic fish, PCB concentrations range from 0.01 to 1 ppm (*Waldbott, 1978*). A more extreme situation lies in the Great Lakes, where coho salmon have had concentrations exceeding 5 ppm (*Waldbott, 1978*). Toxicities also vary substantially from species to species; among aquatic organisms, indications are that in some cases PCBs are more toxic to invertebrates than to fish (*Mayer et al, 1985*). Moreover, studies indicate that earlier life stages are more susceptible to damage (*Mayer et al, 1985*). Some of the potential effects include suppression of avian and mammalian immune responses, increase disease incidence, cancerous tumors, and fin erosion (*Mayer et al, 1985*). The bioconcentration of PCBs is more pronounced in fish-eating birds. Cormorants and ospreys have been found with PCB concentrations ranging

TABLE 3

Evidence for Carcinogenic Effects of PCBs in Mice

Mouse Strain	Sex	No. Treated	No. Surviving	PCB Source	Dietary Level ppm	Average Daily Dose mg/kg/day	Exposure Time (Days)	Liver Nodules: Adenofibrosis	Liver Nodules: Neoplastic Nodules	Liver Nodules: Hepatoma	Liver Nodules: Hepatocellular Carcinoma
dd (Ito, et al. 1973; Nagasaki, et al. 1972)	M	12	12	Kanechlor 500	500	82.5[a]	224	-	7/12		5/12
		12	12	"	250	41.3[a]		-	0/12		0/12
		12	12	"	100	16.5[a]		-	0/12		0/12
				Kanechlor 400	500	82.5			0/12		0/12
				"	250	41.3			0/12		0/12
				"	100	16.5			0/12		0/12
				Kanechlor 300	500	82.5			0/12		0/12
					250	41.3			0/12		0/12
		6	6	Control	100	16.5			0/6		0/6
Balb/cJ (Kimbrough and Linder, 1974)	M	50	22	Aroclor 1254	300	49.8	330	22/22	-	9/22	
		50	24	"	300	49.8[b]	180[c]	0/24	-	1/24	
		100	58	"	-	-	-	0/58	-	0/58	

[a]Calculated using food consumption data from Kimbrough and Linder (1974) for Balb/cJ mice which indicates an average of 165 g/kg/day

[b]Not calculated directly, but assumed to be similar to group exposed 330 days

[c]Maintained on control diet for remaining 150 days of experiment

Source: US EPA, 1980.

TABLE 4

Evidence for Carcinogenic Effects of PCBs in Rats

Strain	Sex	No. Treated	No. Sur-viving	PCB Source	Dietary Level ppm	Average Daily Dose mg/kg/day	Exposure Time (Days)	Liver Nodules: Adeno-fibrosis	Liver Nodules: Neoplastic Nodules	Liver Nodules: Hepatocellular Carcinoma
Donryue (Kimura and Baba, 1973)	M	10	10	Kanechlor 400	38.5-16	13.5[c]	339[a]	-	0/10	-
	F	10	10	Kanechlor 400	38.5-16	17.5[d]	425[b]	-	6/10	-
	M	5	5	None	-	-	-	-	-	-
	F	5	5	None	-	-	-	-	-	-
Wistar (Ito, et al. 1974)	M	*	13	Kanechlor 500	1,000	49.0[e]	378	4/13	5/13	-
			16	"	500	24.5		0/16	5/16	-
			25	"	100	4.9		0/25	3/25	-
			10	Kanechlor 400	1,000	49.0		2/10	3/10	-
			8	"	500	24.5		0/8	0/8	-
			16	"	100	4.9		0/16	2/16	-
			15	Kanechlor 300	1,000	49.0		2/15	0/15	-
			19	"	500	24.5		0/19	0/19	-
			22	"	100	4.9		0/22	1/22	-
			18	None	0	-	-	0/18	0/18	-

TABLE 4 (cont.)

Strain	Sex	No. Treated	No. Sur-viving	PCB Source	Dietary Level ppm	Average Daily Dose mg/kg/day	Exposure Time (Days)	Proliferative Changes: Nodular Hyperplasia	Proliferative Changes: Hepatocellular Carcinoma and Adenoma	Proliferative Changes: Combined Hematopoietic and Liver
Fisher 344 rat (NCI, 1978)	M	25	24	Aroclor 1254	0	0	-	0/24	0/24	5/24
			24		25	1.38[e]	735	5/24	0/24	2/24
			24		50	2.75[e]	735	8/24	1/24	9/24
			24		100	5.5[e]	735	12/24	3/24	12/24
	F	25	23		0	0	-	0/23	0/23	4/23
			24		25	1.38[e]	735	6/24	1/24[g]	13/24
			22		50	2.75[e]	735	9/22	1/22	8/22
			24		100	5.5[e]	735	17/24	2/24	9/24

TABLE 4 (cont.)

Strain	Sex	No. Treated	No. Surviving	PCB Source	Dietary Level ppm	Average Daily Dose mg/kg/day	Exposure Time (Days)	Liver Nodules: Adeno-fibrosis	Liver Nodules: Neoplastic Nodules	Liver Nodules: Hepatocellular Carcinoma
Sherman (Kimbrough, et al. 1975)	F	200	184	Aroclor 1260	100	4.5[f]	630	-	144/184	26/184
	F	200	174	None	-	-	630	-	0/173	1/173
Sherman (Kimbrough, et al. 1972)	M	10	10	Aroclor 1260	1,000	71.4	240	2/10	-	-
	F	10	10	"	100	7.2		1/10	-	-
		10	8	"	500	38.2		1/9	-	-
		10	2	"	1,000	72.4		4/7	-	-
	M	10	10	Aroclor 1254	100	6.8		1/10	-	-
		10	10	"	500	36.4		10/10	-	-
	F	10	10	"	100	7.5		7/10	-	-
		10	9	"	500	37.6		9/9	-	-

[a] range 159-530

[b] range 244-560

[c] range of cumulative intake 450-1800 mg

[d] range of cumulative intake 700-1500 mg

[e] Data not provided. Calculated from Kimbrough, et al. 1975, in which Sherman rats showed similar weight gain over the same experimental period.

[f] Time weighted average calculated from *Figure* 2 in Kimbrough, et al. 1975

[g] Reported as undifferentiated carcinoma of the liver, metastatic

*290 animals total in 10 groups

Source: US EPA, 1980.

from 300 to 1000 ppm (*Waldbott, 1978*).

In an EPA study, newly hatched fathead minnows were exposed to Aroclor 1248 at various ambient concentrations over a thirty day period. Results shown in table 5 indicate that at least 75 percent survived when the ambient concentration was 5.1 micrograms per liter or less, but none survived at 18 micrograms/l. (Data points between these two values were not documented, so a toxicity "threshold" could not be ascertained from this data set.) The study concluded that with respect to fish, PCBs are acutely toxic, but that chronic toxicity is an even greater concern due to the bioaccumulative tendencies of these chemicals (*US EPA, 1977*). An interesting finding was that fish eggs were apparently quite resistant or impermeable to PCBs; but again, the newly hatched fish were the most vulnerable relative to other life stages (*US EPA, 1977*).

Regulatory Standards/Criteria (excluding hazardous waste sites) Within the last twenty years, the EPA, Food and Drug Administration (FDA), and the National Institute for Occupational Safety and Health (NIOSH) have promulgated and established standards and criteria for concentrations of PCBs in ambient air, ambient water, drinking water, food products, and occupational settings. For ambient water, the criteria is as follows (*US EPA, 1984*):

Expected Increase in Lifetime Cancers	Ambient Water Quality Criteria (mg/l)
10^{-5}	0.79
10^{-6}	0.079
10^{-7}	0.0079

NIOSH has recommended an occupational standard of 1 microgram per cubic meter for a 10 hour per day, 40 hour per week exposure (*US EPA, 1984*). (Promulgation of this recommendation into a standard is still pending.)

TABLE 5. Results of 30-day Survival and Growth Study of Newly Hatched Fathead Minnows (Aroclor 1248)

Mean Measured Concentration (microgm/l)	Initial Number of Animals	Mean Percent Survival	Final Mean Weight (g)	Final Mean Length (mm)
18	20	0	--	--
5.1	20	75	0.36	17.9
2.2	20	85	0.49	19.1
0.54	20	80	0.92	20.8
0.18	20	100	1.47	20.3
0.00	20	85	1.11	18.4

Source: US EPA-600/3-77-034, March 1977.

The FDA regulations for PCBs are summarized in table 6. Also, this agency has set an action level of 2.0 mg/kg for concentrations in fish, a level which primarily targets the Great Lakes (*D'Itri, 1988*).

Summary - PCBs PCBs are a class of chemicals whose use in many applications, coupled with liberal disposal practices, has led to widespread contamination of the environment. Because of their persistence and ability to bioaccumulate, PCBs will remain in the environment for the foreseeable future, even though their production ceased over ten years ago. Various studies indicate that PCBs may cause adverse health effects in humans and ecological endpoints, although the collective results of these studies are inconclusive. Regardless, regulations and criteria have been established to reduce exposures to PCBs.

Hazardous Waste Management

Hazardous waste management has been a rapidly growing field in the last 10 to 15 years. The two principal bodies of legislation for hazardous wastes are the Resource Conservation and Recovery Act (RCRA) of 1976, which entails the "cradle-to-grave" approach for treatment and disposal, and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), commonly known as "Superfund," along with its amendments, the Superfund Amendment and Reauthorization Act (SARA) of 1986. The Superfund legislation deals with remediation of past waste disposal practices which have resulted in widespread environmental degradation. In dealing with most hazardous waste situations, a given site contaminated with one or more substances would be subject to one of these laws. PCBs are somewhat of an exception, however: Regulation of use and disposal of PCBs is covered under the Toxic Substances Control Act (TSCA) of 1976, which singles out PCBs in section 6(e). CERCLA/SARA would apply

TABLE 6. FDA Regulations for PCBs

Commodity	Temporary Tolerances (ppm)
Milk (fat basis)	1.5
Manufactured dairy products (fat basis)	1.5
Poultry (fat basis)	3.0
Eggs	0.3
Finished animal feeds	0.2
Animal feed components of animal origin	2.0
Edible portion of fish and shellfish	5.0
Infant and junior foods	0.2
Paper food packaging material	10.0

Source: US EPA, 1984.

in situations where PCBs were disposed of in an improper manner, although elements of TSCA would be used in determining the "applicable or relevant and appropriate requirements (ARARs)". PCBs have been found in about 24 percent of the Superfund sites for which Records of Decision (ROD) have been passed (*Hanson, 1988*). Also, in a survey of 34 Superfund sites, PCBs were designated as an indicator chemical on 13 occasions (38% - *Zamuda, 1989*).

As mentioned earlier, TSCA governs the treatment and disposal of PCBs. Table 7 presents an example of the <u>principal disposal requirements</u> for the remedial action approved for the Pacific Hide and Fur site in Idaho (*US EPA, 1980*), and table 8 summarizes the EPA rules for PCB transformers. As indicated, TSCA divides cleanup requirements into three categories according to the PCB concentration: less than 50 ppm, between 50 ppm and 500 ppm, and greater than 500 ppm. For less than 50 ppm PCB wastes, no special actions are required. For the intermediate category, PCBs are to be incinerated or disposed of in an approved chemical landfill. If the waste contains PCBs in concentrations above 500 ppm, then incineration is the only allowable disposal means. One is not allowed to dilute the wastes in order to reduce the concentration to a level requiring less stringent handling and treatment (*McGraw, 1984*).

<u>Remediation Expenses</u> The cost consequences of these requirements are significant. For instance, disposal in a landfill can cost approximately $300,000 dollars for 1000 cubic yards of bulk waste with PCB concentrations below 500 ppm; incineration costs can be much greater, perhaps up to 1 million dollars (*Freeman, 1989*).

A recent local situation serves as an illustration. Seattle City Light had stored at the Lake Union steam plant approximately 811,000 gallons of heating oil that was contaminated with an average of 75 ppm PCBs. Several alternatives were proposed to eliminate the material, two of which were biological treatment

TABLE 7. Applicable or Relevant and Appropriate Requirements for PCB Superfund Site, Pacific Hide and Fur, Idaho

Chemical-specific	40 CFR 761.60 (a) (4)	Requires that soils contaminated over 50 ppm of PCBs be handled as a TSCA regulated material
	EPA ambient water quality criteria	Establishes a human lifetime cancer due to ingestion of water containing PCBs and aquatic life containing PCBs of 0.079 mg/l at the 10^{-6} risk Establishes aquatic life criteria for PCBs for acute effects (2 micgm per liter) and chronic effects (0.014 microgm/l).
Location-specific	None	
Action-Specific	CERCLA Section 121	Establishes procedures to be observed when a CERCLA response is undertaken involving off-site storage, treatment, or disposal of CERCLA waste. Procedures are outlined in EPA Revised Procedures for implementing Off-Site Response Actions.
	TSCA Regulations	
	40 CFR 761.60 (a)(4)	Requires that soils contaminated at greater than 50 ppm be disposed of in a TSCA regulated incinerator or chemical waste landfill (off-site disposal, landfill design)
	40 CFR 761.60 (b)(2)	Requires that all small PCB capacitors that contain more than 500 ppm of PCBs shall be incinerated unless a determination is made that no incineration capacity exists.
	40 CFR 761.75	Establishes the standards for landfills used for disposal of PCBs.
	40 CFR 761.70	Establishes the standards for incinerators used for disposal of PCBs.

TABLE 7. Applicable or Relevant and Appropriate Requirements (cont'd)

	40 CFR 761.65	Establishes requirements for PCB storage for disposal facilities, including vehicles used for PCB transport.
RCRA Regulations		
	40 CFR 264 Subpart F	Establishes requirements for addressing releases from solid waste management units (landfill design).
	40 CFR 264.310	Establishes hazardous waste landfill closure standards (landfill design).
OSHA Regulations		
	29 CFR Subpart 1910.120	Establishes worker protection standards for employees involved in operations at CERCLA sites.
National Ambient Air Quality Standards for Particulate Matter		
	40 CFR 50.6	Establishes national primary and secondary ambient air quality standards for particulate matter.

Source: US EPA/ROD/R10-88/015 (US EPA (1988b))

TABLE 8. Summary of EPA Rules Governing PCB-Related Transformers

Transformer Categories		
Non-PCB	**PCB-Contaminated**	**PCB**
Distinction between transformer categories		
Fluid Concentration below 50 ppm (F.R. vol 44, no. 106, p 31517)	Fluid Concentration between 50 ppm & 500 ppm (F.R. Vol. 44, No. 106, p. 31517)	Fluid concentration greater than or equal to 500 ppm (F.R. Vol. 44, No. 106, p 31517)
PCB marking and labeling requirements		
No labeling required (F.R. Vol 44, No 106, p 31517)	No labeling required (F.R. Vol 44, No 106, pp 31512 & 31548)	Labeling required (F.R. Vol 44, No 106, p 31548)
Inspection program		
Not required (F.R. Vol 47, No 165, p 37346)	Not required (F.R. Vol 47, No. 165, p 37346)	Required (F.R. Vol 47, No 165, p 37346)
Restrictions on servicing and/or rebuilding		
No restriction (F.R. Vol 44, No 106, p 31517)	Any servicing must be performed by the owner or operator or service company that has obtained exemption (F.R. Vol 44, No 106, p 31518)	Any servicing that requires the removal of coil from tank is prohibited (F.R. Vol 44, No. 106, p 31518; Vol 47, No 165, p 37346)
Disposal of transformer carcasses		
No restrictions (F.R. Vol 44, No. 106 p31517)	No restrictions (F.R. Vol 44, No. 106, pp 31546, 31547)	Must be disposed of in the following manner: Annex II chemical waste landfill or incinerator (F.R. Vol 44, No. 106, p 31546)

TABLE 8. (cont'd)

Disposal of the insulating fluids		
No restrictions, except that fluids with any detectable PCB cannot be used as a "sealant, coating, or dust-control agent" (F.R. Vol 44, No 106, pp 31517, 31524)	Must be disposed of by one of the following methods: Annex II chemical waste landfill; high efficiency boiler; or Annex I incinerator (F.R. Vol 44, No 106, pp 31519, 31520, 31545)	Must be disposed of in an Annex I incinerator (F.R. Vol 44, No 106, p31545)

Source: McGraw, 1984.

and on-site incineration. The former alternative was estimated to cost 1.2 million dollars, whereas the latter (which was later chosen) was expected to cost 4 million dollars (*City of Seattle, 1985*). There may be other situations, however, where incineration may be more cost effective (e.g. operations and maintenance costs may be quite high and render an alternative more costly in present value terms - *Hall, 1988*).

There are a number of factors which influence the total costs of remedial activities. Table 9 lists some of these factors. The type and quantity of waste(s), degree of hazard, site characteristics, age of site, and proximity to at-risk populations all factor into the total price. Politics and public involvement (or lack thereof) also play a role. In at least one case involving the cleanup of an old Alcoa site, proper communications with the public in effect "enhanced" the assessment and cleanup process, thereby helping to keep costs in check (no estimates of cost savings were provided) (*Sonksen and Crawford, 1988*).

In general, hazardous waste legislation includes stringent requirements which lead to significant costs borne by waste generators, the government, and society as a whole. The costs for remedial activities at particular sites can range from a few hundred thousand dollars to 50 million dollars in some cases. With the promulgation of SARA, the costs are expected to increase further. The EPA has estimated that the institution of SARA requirements will increase the average time required for a remedial investigation/feasibility study (RI/FS) from sixth months to two years, and that an average of 67 months will be necessary for remedial activities, resulting in a total time of 6.5 years (*Hellman and Hawkins, 1988*). The average cost per site is projected to rise from 8 million dollars to 25-30 million dollars (*Hellman and Hawkins, 1988*). Table 10 illustrates the ranges of unit costs for cleanup of a site contaminated with PCBs (*Hellman and Hawkins, 1988*).

TABLE 9. Factors Affecting Disposal Costs

A. Excavation or On-Site Transfer
   1. Excavation depth
   2. Site surface characteristics
   3. Waste explosivity
   4. Material-liquid/solid/drums
   5. Waste quantity

B. Transportation
   1. Distance to disposal facility
   2. Accessibility to road
   3. Material-liquid vs. solid
   4. Waste quantity

C. Disposal

   1. PCB
      a. Concentration over/under 500 ppm
      b. Material-solid vs. liquid

   2. Non-PCB RCRA Hazardous
      a. Solid vs. liquid
      b. Aqueous vs. organic

II. Non-Technical
   A. Community relations
   B. Interstate relations
   C. Inflation and regulatory factors

Source: Werner et al, 1983.

TABLE 10. Cleanup Options and Costs for PCB-Contaminated Soil (100 ppm PCB)

Treatment	Estimated Cost/cu. yd.
Landfill - no pretreatment	$200 - $400
Fly ash/cement stabilization	$60 - $80
Fixation onsite with inorganic polymer/cement mixture	$180
Chemical destruction onsite	$200 - $250
In situ vitrification (glassifying the soil) maxtrix with complete destruction of PCBs	$200 - $250
Incineration of soil onsite (PCB destruction)	$200 - $300

Source: Hellman and Hawkins, 1988.

Determining Cleanup Levels At times, the various bodies of legislation may conflict with each other as to what actions should ensue to assure an adequate cleanup. As a result, confusion and disagreement may exist as to what constitutes acceptable levels of cleanup for a given site (*Santos and Sullivan, 1988*). This situation is commonly referred to as the "how clean is clean" issue. Two key aspects of CERCLA that deal with this concern are (1) if for a given site there are several feasible options for remedial activity which will reduce residual concentrations to "acceptable" levels, then the lowest cost option should be chosen (i.e. most cost effective option); and (2) that in determining cleanup levels, all "applicable or relevant and appropriate requirements (ARARs)" should apply, meaning standards and criteria stipulated in regulations such as the Clean Water Act, the Safe Drinking Water Act, and the Clean Air Act (*Wentz, 1989*). This is often an area of controversy, because disagreement often exists as to which laws, standards and/or criteria should apply in a given situation. Such disagreement exists in part because many of the standards incorporated from existing laws and regulations were derived as overall requirements, not explicitly for a localized site (*Santos and Sullivan, 1988*). Also, standards/criteria do not exist explicitly for groundwater or soils (*Santos and Sullivan, 1988*). The EPA and other involved parties are often left with the problem of calculating what residual contaminant concentrations in soil can be allowed to keep surface water and/or ambient air contaminant concentrations below acceptable levels, a task whose difficulty is exacerbated by the various sources of uncertainty such as hydrogeologic conditions, fluctuations in rainfall and infiltration, values of constants used in determining adsorption or desorption potential, etc. (*Santos and Sullivan, 1988*).

The difficulties involved in establishing appropriate cleanup levels are manifest in the RI/FS process, which can take

several years to complete. The delays caused by this process, coupled with legal problems and the sheer backlog of work on the part of the EPA, have resulted in the promulgation of only 130 records of decision (RODs) (up to 1984), even though there are over 900 sites on the National Priority List (NPL) (*Hellman and Hawkins, 1987*). Such delays may result in contamination spreading even further, depending on site conditions, the nature(s) and amount(s) of the chemical(s) involved, proximity of target populations, etc. This spreading may then lead to more extensive cleanup operations, thus increasing the total cost of remediation.

Another issue in deciding cleanup levels is what should be designated as the "point of compliance?" A party responsible for the site would typically prefer it to be at the property boundary or point of impact, whereas those affected would argue for it established at the point of release. Obviously, the choice could greatly change the extent, expense and effectiveness of a given remedial activity (*Greer, 1987*).

Not only is the point of compliance a significant factor, so is the potential future use of the site in question. Ignorance of this factor could substantially reduce cost effectiveness (*Hirschhorn, 1988*). The ramifications go beyond environmental and public risks; they also may influence property rights and values (*Hellman and Hawkins, 1988*).

Linking Remediation Costs and Cleanup Levels From the perspective of a generator, higher cleanup costs may be preferable in some cases, because more extensive remedial activity is likely to reduce residual contamination levels, which in turn may reduce the costs and/or likelihood of litigation against the waste generator. The desire of a given waste generator is to minimize its total costs, thereby striking a balance between these two major cost items (*Hellman and Hawkins, 1988*). However, more stringent cleanup levels would likely increase the time needed

for cleanup, which may in turn increase the risks associated with exposure and consequently the likelihood of litigation (*Hellman and Hawkins, 1988*). Such is the responsible party's dilemma.

A key element in the RI/FS program is the conduct of a risk assessment to aid in determining the potential effectiveness and extent of remedial alternatives. The next section discusses this area with emphasis on weaknesses of the methodologies employed.

Summary - Hazardous Waste Management Several bodies of legislation have been enacted to reduce contamination of the environment with hazardous wastes (including PCBs), as well as remediate contamination due to inadequate disposal practices. Fulfillment of the requirements called for in these laws can be very costly to the responsible parties and society as a whole. The establishment of cleanup levels for a given hazardous waste site can be a very complex task, and may lead to overly stringent requirements which could substantially increase the costs of remediation.

General Aspects of Risk Assessment

The estimation of the risks borne by potentially affected populations due to exposure to various compounds is an essential part of hazardous waste management. The EPA has conducted risk assessments for predicting potential increases in human cancer incidences on regional as well as site-specific levels. Consulting firms and other agencies have conducted risk assessments for hazardous waste sites and other situations. The overriding problems with these assessments are a lack of consistency in assumptions and approach, and insufficient data to confidently predict what the true effects will be. This section discusses some of the key issues and problems revolving around risk assessments in a general sense.

Although not stated exactly the same way in every case, most human health risk assessments consist of <u>four basic steps</u>: hazard identification, dose-response assessment, exposure assessment, and risk characterization (*Anderson and Henry, 1988*). In the first step, one needs to determine if indeed a hazard exists due to exposure to a given substance. Short term tests, bioassays, and epidemiological studies are the methods typically used. In dose-response assessment, a hypothetical curve or equation is developed to quantify the purported relationship between the magnitude of exposure and degree of adverse effect for a given endpoint (e.g. cancerous tumors). <u>Uncertainties exist</u> because one must usually develop the curve or equation based on insufficient information and an extrapolation from one species to another. For example, the dose-response curves for human carcinogens are usually made based on bioassays using rats, mice or rhesus monkeys, in which the animals are exposed to relatively high doses of the chemical of interest. The size and number of tumors (both malignant and benign) are typically correlated with the discrete amount of chemical to which they've been exposed. Since relatively high doses are used, the scientist must extrapolate down to low dose levels, which are associated with potential chronic effects. (Some believe this is when the scientist stops being a scientist and becomes a soothsayer.) The existence of a "<u>threshold</u>," below which no adverse effects occur, has been subject to great debate, especially for suspected carcinogens (*NRC, 1983*). It is typically assumed that for a suspected carcinogen, exposure at any level poses a risk (*Henningson et al., 1988*).

Epidemiological studies are also used to help determine if a certain hazard exists. Like other methods, the validity of these studies are usually limited by a number of confounding factors, in particular the relatively small population size under study, latency between exposure and measurable effects, competing causes, and boundary crossings (i.e. many people don't stay in

the same place for extended periods of time) (*Houk, 1982*).

Exposure assessment involves determining how people might be exposed, i.e. what are the pathways, either through drinking water, ambient air, as well as how the substance may enter the body (ingestion, inhalation, skin adsorption). This step may be both qualitative and quantitative; it may rely on sampling measurements made at the location of interest or on environmental fate models. The desired end product is an estimate of the potential exposure level(s).

The dose-response and exposure assessments are combined to form the risk characterization. This step involves estimating the degree and likelihood of increased adverse effects. In the most simple terms, risk is a product of the probability of occurrence and the consequences of exposure (*Shih and Arroyo, 1988*). Given the various elements of uncertainty, a range of risk values is more appropriate than one point value (*Paustenbauch, 1989*). To quantify the risks, assessors often use the EPA's guidelines which are very conservative in nature; typically, the only risk estimate reported is the increased incidence of cancer at the 95 percent upper confidence limit (UCL)(*Paustenbauch, 1989*). The agency's guidelines consider risks to be acceptable if they lie within the 10^{-4} to 10^{-7} at this upper limit (*Santos and Sullivan, 1988*). However, the maximum likelihood estimate (MLE) (i.e. a more realistic estimate) is often several orders of magnitude below the UCL (10^{-8} to 10^{-12} is not uncommon). The degree of uncertainty in these calculations is obvious.

Despite the large uncertainties and very conservative approach, risk assessments are useful in terms of prioritizing problems and helping determine adequate cleanup levels for hazardous waste sites. However, there are even more issues/problems associated with risk assessments which shall be described below.

One problem of risk assessments is that in most cases they are limited to human endpoints, cancer in particular. To fully address all risks associated with a particular environmental problem, one should also consider the following:

- The adverse health effects to humans other than cancer

- The risks to the ecosystem, such as fish, water quality, flora and fauna

- The risks to the polluter/responsible party (e.g. costs borne via remedial activity and/or potential litigation)

- Risks to the involved government agencies (e.g. EPA's decisions on resource allocation, potential for bad publicity, inappropriate choice of a risk management approach)

Ecological risk assessments constitute a less mature discipline relative to human health risk assessments. All but ignored in the past, the EPA has indicated that it will in the future step up the effort to address this concern. Of course, the same problems associated with human health risk assessments will be manifest in this area; in some cases, those problems will be magnified. For instance, determining a dose-response curve for certain flora or fauna may be even more difficult, if not impossible. Some species could be tested directly under laboratory conditions, but for others this approach may not be practical or affordable. (The EPA's Office of Research and Development has produced dose-response curves for toxicity of some chemicals to many important aquatic organisms, but little data exists for terrestrial creatures - *Pavlov, 1989*). Even if it were possible to test all species individually, the results would have limited validity due to the dynamic interactions of the species constituting a given ecosystem.

What might be a prudent approach to addressing ecological risks? *Barnthouse et al* have tried to address this issue and have developed a user's manual for ecological risk assessment (*Barnthouse et al, 1986*). Although this manual was developed with synthetic fuels in mind, it serves as a guideline or at least a starting point for risk assessments of other chemicals. With this guideline as a foundation, I suggest the following approach:

(1) Identify critical endpoints (e.g. LC_{50}),

(2) Gather whatever existing data is available on the species of interest,

(3) Identify data deficiencies and uncertainties,

(4) Use existing models such as SWACOM and/or conduct field investigations if feasible, to estimate exposure levels and potential effects,

(5) Estimate the risks of ecological damage.

"Endpoints" as such will be broader than those used for human health assessments; for instance, significant decreases in populations of important species and/or disruptions in the ecosystem structure and function could be considered (*Barnthouse et al, 1988*). Other possible endpoints are species succession, changes in behavior (growth, feeding) of important organisms, decreased metabolism, etc. With this in mind, an ecological risk assessment should consider a number of factors, including the possible involvement of endangered species, and the fact that some species may be critical to the ecosystem even if not perceived to be important to society (zooplankton, macroinvertebrates, etc.). In the end, it will be up to the risk managers to

determine acceptable levels of environmental damage (if any).

A Critical Look at Risk Assessments Again, the credibility of a given risk assessment is limited by the degree of uncertainty which inevitably exists. Table 11 lists some of the primary factors which contribute to uncertainty, much of which we may never be able to reduce by any substantial degree. (Any or all of these factors could apply to a situation involving PCB contamination.)

Silbergeld (1987) singled out several areas of uncertainty which hamper the abilities of risk managers to make prudent choices. First, all chemicals believed to be carcinogenic are treated the same, when in fact their effects and mechanisms warrant different treatments. Specifically, some act as "initiators" (directly affecting genetic material), whereas others are "promoters" (affecting an organism only after exposure to an "initiating event"). *Silbergeld* argues that this lack of distinction hurts risk management efforts because potential carcinogens may not be detected properly, and there may be a failure to recognize the threat posed by background levels of promoters, compounds for which there is currently insufficient effort to identify which chemicals act in such a manner.

Second, statistical analyses to derive population risks from individual risk assessments are flawed. Most risk calculations are performed for one "average" individual; often the resulting risk value is multiplied by the number of people supposedly exposed to that level of risk. This simple approach doesn't account for true variances in exposure scenarios, the importance of time, variations in metabolism between individuals, etc. *Silbergeld* contends this approach may underestimate the true risks to an individual due to a "safety in numbers" situation.

Third, the extent of data available on a chemical's potential toxicity (i.e. the weight of evidence) may not be utilized properly. She suggests using such weight of evidence as a basis

TABLE 11. Assessment Elements and Uncertainties

Category	Element	Uncertainty
Sources and Releases	Type Quantity Concentrations Form Local conditions	Measurement Error Sampling Error Chemical use practices Historical conditions Sources Background concentrations Choice of chemicals to include for lab analysis Variability (temporal & spatial)
Environmental Transport & Fate	Environmental media (air, soil, water,biota) Transport within a medium Transfer between media Transformation	Physical properties of media & Biological properties of chemicals Limits on chemicals to include in the assessment Advection, dispersion rates Partitioning between media Rates of mass transfer
Exposure Assessment	Exposure routes (inhalation, ingestion, dermal contact) Exposure point concentrations Receptor activities Intake rates of environmental media Populations	Intake rates: USEPA has used 2 L/day for water ingestion, 20 m3/day for air inhalation and 6.5 gm/day for fish ingestion Exposure frequency Exposure duration Limits on chemicals to include
Toxicity Assessment	Population Metabolism Dose-Response relationships	Variety of effects Assessments available for relatively few chemicals Extrapolations Animal-to-man High-to-low dose Structure-activity relationships Synergism/antagonism Individual sensitivity Cancers have different impacts on expected lifetime Absence of quantitative toxicological data on tested chemicals
Risk Characterizations	Combines all of the above elements	Combines all of the above uncertainties

Source: Lincoln, 1987.

for <u>prioritizing chemicals</u> may inhibit the identification of more dangerous compounds. If a chemical is truly hazardous, but little evidence has been developed to determine so, attention and expenditures may be diverted to concerns which actually should receive less relative effort.

Fourth, using <u>single values for potency factors</u> can be misleading. For one, linear regression analyses lead to this single value for a given chemical, when its potency actually varies with level of exposure. Moreover, a toxin with a relatively high potency factor may receive more attention even though exposure level may be the overriding factor.

Typically, risk assessments are conducted vis-a-vis one chemical. What about the <u>presence of other chemicals and surrounding exposures</u>? Are they additive, synergistic, or antagonistic? The EPA assumes that the risks posed by all carcinogens are additive (Zamuda, 1989). Likewise, the risks posed by a given compound via several pathways are usually considered additive. While it may be difficult to determine the true nature of interactions between compounds, simply assuming additive interactions may compound the overestimation or underestimation of risk. Moreover, when assessing the risks in a given situation, one should look beyond the risks posed only by the direct anthropogenic input, and consider the risks posed by background contaminant concentrations. For instance, exposure to a contaminant and the preexisting levels may be below an acceptable level (if non-carcinogenic); but what if that incremental amount of exposure pushes the total exposure above that which is considered allowable? Risk assessments should address this question.

In making risk calculations, <u>point values of relevant chemical properties</u> are often used (e.g. half-life). These values are usually derived in laboratory experiments, whose conditions are often very different from those found in the field. Many confounding factors exist (pH, temperature, oxygen

availability, etc.), factors which usually do not remain constant over time. The constants used in risk calculations may therefore be inaccurate, potentially leading to an overestimate or underestimate of the true risks (*Paustenbauch, 1989*).

Even if technical methods and a "risk database" were well developed and integrated, and uncertainties were subsequently reduced, much of this effort could be rendered useless due to one major influence: the perception of the public. This factor is exemplified by the concern over Alar, wherein one study which may or may not have been biased resulted in overconcern on the part of the public and caused a tremendous economic loss for the apple industry (a case of "crying wolf," perhaps). Once rumors grow over the possible dangers of a substance, whether it is truly hazardous or not, government and industry are forced to act. Even with PCBs, the threat may be exaggerated, because for the most part no statistically significant increases in adverse effects have been identified in those subjects who have significantly higher levels of PCBs in their systems (*Stehr-Green et al, 1986b*). So public perception is a factor which must be considered in any risk assessment (at least in a qualitative manner). This is why many private parties treat risk assessment documentation as confidential, lest they find themselves mired in lawsuits and exorbitant, excessive remedial response actions.

With all these deficiencies, are risk assessments of any real value? One author made this observation:

> Risk assessments are most effective when used as a tool for organizing the best available scientific and technical information about a particular exposure problem, to assist in informing decisionmakers about the consequences of alternatives, not when the objective is to obtain a specific risk value (*Lincoln, 1987*).

Noted previously was the fact that risk assessments are rarely if ever complete. Lincoln also noted that

> ... the permutations and potential resource requirements for performing a 'complete' risk assessment for a general site condition are quite large. Unfortunately, there is no generally accepted 'stopping rule' that describes

> when there is enough information to perform a risk assessment that meets the study objectives ... The stopping point would be when the marginal resource requirements of the risk assessment exceed the marginal gains in distinguishing between the two alternative actions.

Using such a "stopping point" would be more or less a value judgement; moreover, there are typically more than two alternative actions, a reality which would further complicate determining the so-called stopping point.

At most sites, there exists more than one hazardous waste. Should a complete risk assessment be carried out for each substance? This would likely be an inefficient and unnecessary approach. Santos and Sullivan commented on this manner:

> If volatile, semi-volatile or inorganic compounds all present significant health risks, it may only be necessary to select one or two compounds from each class for development of the target level. Usually the most recalcitrant compounds will be chosen to assure that the treatment methods are effective even on the compounds most difficult to treat.

What is the true purpose of conducting a risk assessment? It is to provide decisionmakers sufficient information to allow them to pursue a risk management approach that protects humans and the environment at the lowest possible cost. It is the responsibility of risk managers to decide which options to pursue to mitigate and prevent potentially harmful effects on humans and the environment. A comprehensive risk assessment, in conjunction with knowledge of other factors such as public sentiment, the ability to identify responsible parties, etc., is necessary for risk managers to accomplish their tasks.

Several options are available to the risk manager when determining a remedial response for a given hazardous waste problem (*Hellman and Hawkins, 1988*):

- Remediate to achieve or exceed cleanup standards
- Contain or control entry
- "Educate" the public
- Do nothing

The choice of one or a combination of these options will depend on the quality and quantity of information available to the risk manager. As pointed out already, this information is often incomplete, typically leading to a conservative (perhaps overconservative) approaches. The irony is that such conservative approaches may decrease safety because resources may be allocated to areas of concern which are truly of lesser priority (*Maxim, 1989*). Likewise, Collins and LeClare noted:

> On the one hand, risk management decisions that rely on the cost-effectiveness ranking of options ... without health risk assessments cannot assure protection of public health. On the other hand, the use of a risk assessment approach to identify unacceptable risks but not to identify potentially acceptable levels of risk, leads to the situation as in Times Beach where the only governmental choice can be to take the lowest risk option. The proposition is put forward that without an identified and quantified level of acceptable risk, risk management decisions remain essentially qualitative decisions regardless of the degree of cost-effectiveness or risk assessment input.

All in all, there is great controversy over the validity and utility of present-day risk assessments. One author stated that "... risk assessment is the major issue that hampers progress." (*LeGrand, 1981*) Others claim that risk assessment is really an art (even "black magic"), not a science. Despite such cynicism, risk assessments will continue to play an important role in hazardous waste management. Their need is called for in prioritizing hazardous waste sites, determining cost effective cleanup levels, etc. Continuing efforts to improve their accuracy and precision should lead to more consistent approaches, thus enhancing the credibility of risk assessments.

In light of the advantages and disadvantages of risk assessments, it is undoubtedly possible to improve the quality (and thus, the credibility) of risk assessments to enable more prudent approaches to risk management. While much of the criticism of risk assessments as depicted in the literature is warranted, risk assessment will remain an important element in reducing and preventing harm to humans and the ecosystem. However, modifica-

tions to the approaches will be needed. It would be ideal if sufficient time and money were available to conduct more stringent bioassays and epidemiological studies. I question whether improvements will be made in these areas. If we continue to use overconservative approaches to establish standards and cleanup levels, the effects of exposure to toxic chemicals are less likely to become manifest in epidemiological studies, because remedial actions will reduce exposure levels to well below those which are truly necessary; the ability to determine a true causal relationship between exposure and endpoint will hampered even further. In other words, we may never be able to determine if risk management efforts as chosen are truly effective. This is not to say that we should allow the general population to continue to be exposed to potentially very damaging levels of contaminants; but to allow risk managers to be more objective in their decisionmaking, improvements in risk assessment procedures are warranted. One of the areas which is most amenable to improvement is the development of more realistic case scenarios of exposures to obtain more accurate estimates of risks. For example, variances in exposure levels could be postulated; durations of exposure could be made parametric rather than just 70 years.

There will be a limit, however, in how far one can go in narrowing the uncertainties involved. Many risk analyses depend on complicated models for determining environmental pathways and fate of the chemicals of concern. At best, most of these models are valid only within an order of magnitude, due to problems such as modeling groundwater transport through heterogeneous media, assumed values for half-lives and adsorption constants, etc. The marginal costs for improving these models eventually outweighs the marginal improvements in accuracy, as Lincoln indicated. This may very well be the "stopping point" to choose.

<u>Summary - Risk Assessments</u> Risk assessments are an integral part of hazardous waste management; they factor into the priori-

tization of hazardous waste problems and the selection of remedial action alternatives. Unfortunately, present day methodologies for risk assessment are based on insufficient information; inherently conservative assumptions often lead to substantial overestimations of risk, a situation which may spawn excessive remedial efforts.

HYPOTHETICAL CASE STUDY

The purpose of this hypothetical case study is to (1) provide analytical evidence supporting the notion that it is in the best interests of a waste generator to use proper disposal practices for a given quantity of hazardous waste, rather than dispose of the same in a negligent manner, and (2) to illustrate present-day practices in risk assessments along with the attributes and pitfalls thereof. Although the scenario is hypothetical, the data and methodologies used in it are based on those reported in the literature, in particular the following documents:

- Superfund Record of Decision (ROD) for LaSalle Electrical Utilities, Illinois (PCB and volatile organic chemical contamination within the vicinity of 190 people and four aquifers; present worth cost of remedial action is approximately $35 million)

- Superfund Records of Decision (ROD) for Pacific Hide and Fur Site, Idaho (eleven acre site; present value of remedial action is between $1.3 million and $1.9 million)

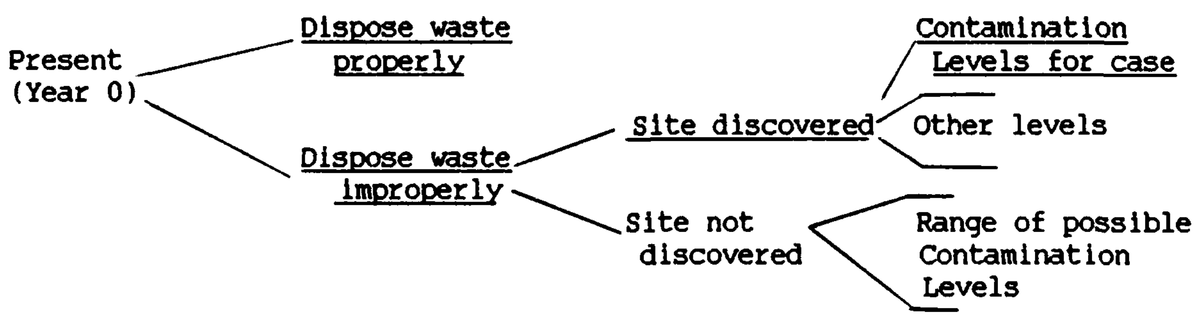
- Northwest Transformer (Whatcom County, Washington) Remedial Investigation and Feasibility Study Reports (PCB, PCDF, & dioxin contamination in agricultural setting; recommended cleanup to 10 ppm using on-site thermal destruction costing $0.75 million)

- Fort Miller Inactive PCB Disposal Site, New York (2.5 acre remote site consisting of 20,000 cubic yards of waste material; no remedial cost data provided)

- Strandley Scrap Metal/Manning Property Focused Feasibility Study (65 acre site near Burley Lagoon, Washington; PCBs and dioxin present)

The scope of this hypothetical situation is as follows: A waste generator has 10,000 gallons of transformer mineral oil containing an average of 200 ppm PCBs (range 150-300 ppm). The company has obtained an estimate for incinerating the material of approximately one hundred thousand dollars. Instead of pursuing this disposal method, the company is considering "indefinitely storing" the waste material on property it owns in a rural/suburban region with a steadily growing population.

The generator is faced with two basic options: incinerate the waste at a very high initial cost, or merely dispose of it on its remote property, resulting in a very low initial cost, but with potentially high regrets. The following figure is an event tree which graphically depicts the scope of this analysis:



This case only considers the possibilities outlined above. As the figure shows, in actuality there are other possible outcomes, to which each would be assigned a point value probability of

occurrence. These other possibilities are not considered in this scenario.

Groundrules To place this scenario within a meaningful and realistic context, this case study assumes that the waste generator is a generic, private entity of medium size which acts as a supplier of PCB closed system products such as capacitors and transformers. Its customers consist primarily of real estate developers and building contractors; as such, it does not deal directly with the public at large in the marketplace (hence, the demand for its products can be considered inelastic; any bad publicity that would arise from this situation will have negligible impact on sales). The waste generator is self-insured, i.e. it can afford to pay for remedial actions and litigation from a "management reserve" fund. Although the potential costs it would bear that may result from improper disposal are considered significant, they are not so great as to force the company to file for bankruptcy. Since the disposal occurs on its own property, and this company is the only contributor of waste at this particular site, it is assumed that evidence (property ownership records, labeled containers, etc.) is strong enough to clearly establish a link between the contaminated site and this waste generator. Therefore, the likelihood of facing the regrets associated with this activity is all but certain.

The end product will be a cost comparison of one immediate, proper disposal option to three alternative measures resulting from improper disposal. Inherent in this cost comparison are risk assessments of the potential hazards to both the proximate human population and the surrounding ecosystem. It will be shown that while both require the employment of limiting assumptions, the latter is even more difficult to perform with any confidence due to deficiencies in techniques for quantification of the various risks and the limited availability of data needed to perform the assessment.

The results of these risk assessments will be converted into potential cost liabilities for the waste generator. As such, this case study assumes that the risk assessments are conducted by and for the waste generator; in particular, the human health risk assessment will be conducted in a fashion similar to those presently conducted by the EPA and consulting firms using EPA guidelines. In essence, the risk assessment as conducted by the waste generator is intended to answer this question posed by the waste generator: If the site contamination is discovered, with remedial actions, possible fines and litigation following, what would be the scope, content and results of a quantitative risk assessment that might be used as evidence for probable harm to human health and the ecosystem? In other words, it gives the waste generator a chance to foresee how strong the evidence against it would be.

Case Study Framework This case study consists of the following steps:

- Proper disposal Estimate cost of immediate disposal
- Improper disposal
  - -- Characterize the site and its potential hazards
    - --- Determine volume, concentration, area and depth of contamination
  - -- Separately assess the risks to humans and the ecosystem

    Human Health
    - --- Identify pathways and relative contributions to total exposure (air, water, soils, foods)
    - --- Estimate PCB intake levels
    - --- Estimate risk of increased incidence of cancer

    Ecological
    - --- Identify general organisms of interest
    - --- Calculate the percent reduction in biomass due to possible acute, chronic and indirect (reduction in prey biomass) effects
    - --- Perform the same for the overall ecosystem using EPA

chronic and acute aquatic life criteria

- Estimate costs for remedial activities
- Estimate costs/damage to wildlife and cost potential of legal actions against the waste generator (for both ecological and human health considerations)
- Compare the costs of proper disposal to the alternatives associated with improper disposal
- Develop a "base case" based on plausible assumptions, then perform uncertainty analyses

Proper Disposal As described in the literature review, PCB contaminated fluid in the 50 to 500 ppm range can be disposed of in an approved chemical landfill or be incinerated. Based on a telephone conversation with a representative of such a landfill in this region, it is presently not common practice to exercise the landfill option for a waste stream of this nature (*communication with Jack Stone, Waste Management Inc., 1989*). Therefore, for this cost comparison, the method of choice is incineration.

Although incineration is perhaps the most expensive disposal method (unit costs range from $350 to $400 per ton), it the most effective, because it destroys the PCB waste with greater than 99.99% destruction-removal efficiency (DRE - *Freeman, 1989*). Byproducts of incineration may contain hazardous substances such as dioxin, but they are of substantially lower quantity; if any escapes through the stack, the byproducts are likely to be disbursed over a wide area. For purposes of this cost comparison, it is assumed that the incineration facility is located in a relatively remote region, and that plume emissions are spread over a sparsely inhabited region such that the ecological and human health risks can be considered *de minimis* (i.e. so small that they are not worth considering). From the perspective of the waste generator, this assumption is plausible because even if litigation were initiated as a result of concern over the incinerator emissions, the operator of this facility would bear

primary responsibility; moreover, one would face virtually insurmountable technical and legal difficulties in establishing a link between such emissions and the waste generator in question. Therefore, the only costs associated with this option are transportation to the burn facility and the incineration itself (see Appendix A).

Improper Disposal

Given that the waste has been placed on the company's "remote" property, the contamination could adversely affect human health as well as the ecosystem of the locality. It will be assumed that contamination has occurred five years prior to the point in time at which the site is "discovered" by local authorities and the community. As a result of this contamination, increases in concentrations of PCBs in the various environmental media result; the risks that such a situation imposes depend on the various site conditions which are described below. Table 12 summarizes the parameters and inputs for the site, which shall be elaborated on further. (Note: While not all of the parameters will actually be used in the case study, the table illustrates what information is typically documented in an RI/FS; also, the data would be needed if a fate/transport model were used for the exposure assessment. Those directly used in this case are annotated accordingly.)

General site description The area of the site is about three (3) acres, surrounded by woodlands and some agricultural land. Approximately 35 homes and two farms are within 1000 feet of the boundary. A small stream separates the site and the farms; it runs by a cluster of homes, most of which rely on local drinking water wells. Within a two mile radius, three more farms and 100 more homes exist. The stream empties into a small lake 1.5 miles away. The lake is mesotrophic and is stocked yearly with trout and other game fish.

TABLE 12. SITE PARAMETERS

Item	Unit	Average Value	Range
Hydrogeologic			
Soil porosity	% vol	25	15 - 40
Soil permeability	ft/s	10^{-3}	10^{-2}-10^{-6}
Depth to confining layer	ft	10	8 - 15
Depth to groundwater	ft	6	4 - 10
Head drop between landfill and compliance surface	ft	50	0 - 300
Annual rainfall	in	35	25 - 42
Rainfall rate	in/hr	0.1	0.02 - 1
Rainfall duration	hr	2.5	0.5 - 6
Annual infiltration	in	27	20 - 32
Annual evaporation	in	25	20 - 30
Net infiltration	in	10	-5 - 22
Physical			
[R]Area	sq ft	130,000	110,000 - 150,000
Distance to stream	ft	1000	--
Distance to lake	mi	1.5	1 - 2
Elevation	ft	400	350 - 430
Radius encircling 150 people	ft	1500	1200 - 1700
Radius encircling 300 people	ft	2000	1800 - 2200
Distance to agricultural land	ft	1000	900 - 1100
Population growth rate (% per year)		15	10 - 25
Climatological			
Temperature	deg F	60	15 - 98
Barometric pressure	in Hg	29.5	27 - 32
Rainfall	in	35	25 - 42
Evaporation	in	25	20 - 32
Snowfall	in	3	0 - 15
Wind speed	mi/hr	5	0 - 30

[R] Required for risk assessment calculations

Climate The climate is similar to that found in the Northwest United States, with generally mild conditions year round. The typical temperature range for a given year is 20 to 90 degrees Farenheit; temperatures beyond these values are rare. Winters are cool, with snowfall averaging 10 inches or less per year. Fall through spring constitutes the rainy season (late September through early May); little precipitation occurs during the summer months. Average rainfall is 35 inches, evaporation (potential) is 25 inches, and infiltration is 27 inches, yielding 10 inches net infiltration and 8 inches of runoff.

Topography/Drainage The site is at an elevation of 400 feet above sea level. It is fairly flat, although it gently slopes downward to the west and north such that runoff occurs in those directions and empties into the nearby stream. The surrounding area (with a radius of approximately 0.5 miles) is slightly hilly (elevation range of 375 to 425 feet); beyond to the south and east is a steeper region (elevations rising up to 800 feet).

Hydrogeology: The groundwater table varies, usually between 10 to 15 feet below the surface. One major aquifer exists in the area. The soil type varies, with organic sandy-silt in the first five to ten feet, followed by glacial till then a relatively impermeable clay-silt layer. The region above the confining layer is moderately permeable (on the order of 10^{-4} to 10^{-6} feet per second). Ground water moves at an average rate of 40 feet per year.

Contamination Assessment Five years after initial disposal, the contamination is discovered. The PCB contaminated fluid is assumed to have been placed uncontained onto the property and has permeated into the soil. The fluid concentration of PCBs is measured and determined to be an average of 200 ppm, with a range of 150 to 300 ppm. The fluid consists primarily of Aroclor 1254 and Aroclor 1260, both of which exhibit a relatively high persistence due to high chlorine content. Soil borings are made to

assess the spread of the contamination. Table 13 lists the maximum depths of several concentrations; it indicates that the PCBs have moved vertically to a depth no greater than 10 feet; some horizontal movement is present, but is difficult to quantify. Some "hot spots" also exist, in which the contamination does not exceed 300 ppm PCBs.

Risk Assessment Methodology

This section follows the risk assessment framework described earlier. The site and associated contamination have been characterized. Next come the exposure assessment, dose-response assessment, and risk estimation. Human and ecological risks will for the most part be discussed separately. However, some portions of the discourse will apply to both, even though they appear under one heading. The risk estimation is first performed for the "no-action" alternative (which represents "present" conditions), then for the two cleanup options (remove all soil contaminated with PCBs at concentrations greater than 10 ppm and 1 ppm, respectively).

Exposure Assessment - General Normally, there are two basic options for conducting an exposure assessment. One is to use fate/transport models to predict concentrations in the media of interest; the other option is to use direct (field) measurements. This case study will rely on the field measurements as reported in the literature, in particular those values which are commensurate with the source contamination levels at hand. (A fate / transport model would be useful if available; however, it would provide little if any gain in accuracy relative to direct measurements; the use of such a model is not required for purposes of this report.)

In reality, the concentrations of PCBs in each medium would vary with time and space. For this exercise, average values as reported are used for the base case. To link the soil contamination levels with the resulting concentrations in the ground-

TABLE 13. FACTORS AND PROPERTIES OF CONTAMINANT (PCB)

Item	Unit	Average Value	Range
Contaminant (PCB)			
Half-life in:			
Air	months	7	4 - 10
Soil	years	2	
Biota		10	1 - 100
Potency	$(mg/kg\text{-}day)^{-1}$		
Human		7.7	4.34 or 7.7
Vapor pressure	atm		$8 - 29 \times 10^{9}$
Water solubility	ppm	0.2	
Henry's Law constant	$atm\text{-}m^3/mol$ (20 deg C)	1.9×10^{-7}	$1.7 - 2.3 \times 10^{-7}$
Site Contamination			
Concentration of PCB in fluid	ppm	200	150 - 350
Volume of fluid	gal	10,000	
Depth of 200 ppm	ft	0.5	0.3 - 1
Depth to 10 ppm	ft	2.0	1.5 - 2.2
Depth to 1 ppm	ft	3.0	2.5 - 4.5
Depth not detected	ft	10.0	7.0 +
Area of 10 ppm contam	sq ft	22500	6750 - 33750
Area of 1 ppm contam	sq ft	32400	9000 - 45000

water, air, and lake/stream water column, appropriate "reduction" factors are employed; the same values are used for all three cleanup alternatives. (See Appendix A.)

Exposure Assessment - Human Humans can come into contact with PCB due to site contamination in one of five ways: air inhalation, soil ingestion, dermal adsorption (soil), ground (drinking) water, and consumption of crops and fish contaminated with PCBs. In assessing the pathways, one must consider the concentrations in each medium resulting from the site contamination in conjunction with pre-existing (background) levels. Table 14 lists these background levels in all media.

In general, many risk assessments involving PCBs have determined that food intake is the primary source of PCBs (although discrepancies do exist in terms of prioritizing the pathways - *Henningson et al, 1988 and Tetra Tech, 1985*). Pathways such as outdoor air and drinking water pose less of a threat due to certain properties of PCBs, namely their propensity to absorb and remain absorbed to soils, along with low solubility and vapor pressure; ingestion of contaminated foods may pose greater risks because of PCBs' tendency to bioconcentrate in living organisms (*US EPA, 1980*). With respect to ground water contamination, unless the ground water table is very high (within 2 to 3 feet of the surface), and/or organic solvents are present, the relative contribution of ground water contamination to human health risk will be low to negligible (*US EPA, 1984*). Likewise, contamination of the ambient air will be small (perhaps insignificant), because PCBs have little tendency to volatilize. Even if air contamination is significant at the source, dilution will reduce concentrations to near background levels once they reach a human target (unless an individual is right on the site and is not protected). Soil ingestion is a potentially high risk pathway; in particular for children whose intake of soil matter may be very high during certain times of the year.

TABLE 14. BACKGROUND PCB CONCENTRATIONS

Item	Unit	Nominal Value	Range
Groundwater	microgm/l	0.03	0.005 - 0.05
On-site soil	mg/kg	0.5	0.2 - 1
Water column	microgm/l	0.002	0.001 - 0.007
Air	nanogm/m^3	0.8	0.1 - 2
Fish	ppm	0.1	0.02 - 0.3
Food crops	ppm	0.1	0.02 - 0.3

Exposure Assessment - Ecological The exposure assessment for ecological endpoints is somewhat similar to that for humans; the differences are that (1) not all of the five previously delineated pathways are necessarily relevant for each species, and (2) the food chain may become a significant pathway for PCB exposure, in particular for those organisms residing at higher trophic levels.

As the food chain takes on greater significance as an exposure route, so do the contaminant concentrations in the stream and lake sediments. PCBs tend to absorb to particulate matter and settle out of the water column, thereby providing potential for uptake by benthic organisms which may bioconcentrate the chemicals (*Thomann et al., 1987*). Given that average runoff is 8 inches per year, transport of PCB from surface soil to the stream and lake beds is a mode of concern. This contamination may increase further in higher trophic levels via predator-prey relationships in conjunction with biomagnification. Such mechanisms may yield significantly higher risks for certain organisms even though the media concentrations of PCBs may appear to be much smaller (*Thomann et at., 1987*). (Note: Unfortunately, data needed to assess the uptake by benthic organisms are not available. Data on benthic macroinvertebrates are of the form of acute and chronic toxicities based on the PCB concentrations in the ambient media (water), not of those found in sediments. Hence, although it is desirable to quantify this route of exposure, attempts to do so here were abandoned.)

Average values of PCB concentrations in the media of interest are delineated below. It is assumed that all PCB contamination above background levels is due to the site contamination.

- Groundwater: 0.010 mg/l
- Stream water & Lake water column: 2.0E-06 mg/l
- Stream & lake sediments: 10 ppm (mg/kg)
- Air within 1000 feet of site: 0.126 mg/m3

Dose-Response Assessment - Human The primary endpoint of concern is cancer. All the risk assessments used in developing this case study addressed carcinogenicity, but none of them addressed any other endpoint such as fetotoxicity or teratogenicity. This simplification can be deemed acceptable if cancer is the endpoint of greatest chronic sensitivity to PCB contamination, or if the estimated risks (existing or post-remediation) are minimal.

For cancer, risk assessments typically assume that no level of exposure is completely safe, and that cancer risk can be estimated using this formula:

$$\text{Risk} = 1 - \exp\left(- \begin{array}{c}\text{average daily}\\ \text{exposure}\end{array} \times \text{potency factor}\right)$$

where the average daily exposure is usually measured in units of milligrams per kilogram-body weight per day (mg/kg-bw/day), and the potency factor has reciprocal units (*Schaum 1984*). The potency factor is based on the steepest slope of the laboratory-derived dose-response curve. For PCBs, both 4.34 and 7.7 have been used in the literature as values for the potency factor. The base case will assume the latter value.

Dose-Response Assessment - Ecological Data are available for PCB exposure causing effects which are grouped into one of two general categories: acute and chronic (*Eisler 1986*). While considerable overlap may exist among these categories (in terms of both level and duration of exposure), they are traditionally viewed as follows:

- Acute: short duration, high exposure level
- Chronic: long duration, low exposure level

Quantification of acute exposure typically involves the experimental determination of the exposure that causes mortality in a relatively short period of time. This exposure is defined as

either the LC $_{50}$ (lethal concentration at which 50 percent of the sample population dies within 96 hours), LD $_{50}$ (lethal dose instead of lethal concentration), or EC $_{50}$. Chronic exposures involve measuring effects other than direct mortality, such as reductions in reproductivity, in growth, and/or in feeding, and even cancer in some instances.

Eisler (1986) tabulated a rather voluminous amount of data on acute and chronic effects of PCBs to various ecological organisms. Obviously, it would be impossible (and unnecessary) to consider all species in this exercise; this case study will take into account the following general categories of organisms (with the exception of specifically using mink, which is considered to be one of the most sensitive organisms to PCBs - *Eisler, 1986*), accompanied by pertinent toxicity data:

(Source: *Eisler, 1986*)

Organism	Acute Toxicity	Chronic Toxicity
Mink	6000 mg/kg	0.64 mg/kg
Invertebrate	0.1 mg/l	0.002 mg/l
Small fish	0.033 mg/l	0.006 mg/l
Large Fish	0.1 mg/l	0.0015 mg/l
Avian	2000 mg/kg	50 mg/kg

(Note: I didn't necessarily pick those organisms that have exhibited the greatest sensitivity to PCB exposure, but those appearing to be most representative and which are likely to be found in this region of the United States. Also, values for toxicities vary considerably even for a given class of organisms; values used here are within applicable ranges.) Effects on plants are ignored since PCBs appear to pose little if any harm to many forms of vegetation (*Mahanty, 1986*). In additicn, table 15 summarizes the recommended values of environmental criteria that are being used or are proposed for use in controlling PCB exposure. Some of these values will be taken into account in the

TABLE 15. Proposed PCB Criteria for Protection of Various Resources & Human Health

Resource and Criterion	PCB Concentration [a]
Aquatic Life	
Freshwater	<0.014 mcgm/l, 24-h average
Saltwater	<0.030 mcgm/l, 24-h average
Fish	
Diets	<0.5 mg/kg (FW)
Residues	
Whole body	<0.4 mg/kg FW
Eggs	<0.33 mg/kg FW
Laboratory Animals	
Rat	<5.0 mcgm/kg BW daily
Dog	<2.5 mcgm/kg BW daily
Rhesus monkey	<1.0 mcgm/kg BW daily
Livestock	
Finished animal feeds [b]	<0.2 mg/kg FW
Animal feed components [c]	<2.0 mg/kg FW
Food packaging materials [d]	<10.0 mg/kg
Wildlife	
Mink	<100 mcgm/kg FW diet <1.5 mcgm/kg BW daily
Birds	
Diet	<3.0 mg/kg FW
Residues	
Eggs	<16.0 mg/kg FW
Brain	<54.0 mg/kg FW
Human Health	
Adult daily intake	<1.0 mcgm/kg BW
Fish and shellfish [e]	
USA	<5.0 mg/kg FW
Canada	<2.0 mg/kg FW
Poultry	
USA	<3.0 mg/kg LW
Canada	<0.5 mg/kg LW

TABLE 15. (Continued)

Resource and Criterion	PCB Concentration [a]
Human Health (cont'd)	
Eggs, whole less shell	
USA	<0.3 mg/kg FW
Canada	<0.1 mg/kg FW
Dairy products	
USA	<1.5 mg/kg LW
Canada	<0.2 mg/kg LW
Fish oil (Canada)	<2.0 mg/kg LW
Beef (Canada)	<2.0 mg/kg LW
Infant & junior foods	<0.2 mg/kg FW
Drinking water [f]	zero
Lifetime safety limit	200 mg
Overt human effects	500 mg
Air	
Occupational, 40-hr week	<1.0 mcgm/m3

[a] FW = fresh weight, BW = body weight, LW = lipid weight.
[b] Except feed concentrates, feed supplements, and feed premixes.
[c] Including fish meal and other byproducts of marine origin, & finished feed concentrates, supplements, & premixes.
[d] Paper products intended for used in contact with human food & finished animal feed.
[e] Excluding heads, scales, viscera, and inedible bones.
[f] The zero drinking water criterion for human health protection is based on the non-threshold assumption for PCBs. However, a zero level threshold may not be attainable at this time. A measurable reduction in potential carcinogenic effects due to exposure of PCBs through ingestion of contaminated water may be effected through ingestion of water containing less than 0.0008 mcgm PCBs/1.

Source: Eisler, 1986.

risk estimation.

Risk Estimation - Human In this section, the exposure assessment and dose-response data are combined to estimate the risks of carcinogenicity resulting from exposure to PCBs. The risks associated with exposure via each medium are separately derived, then are summed to arrive at "total" risk level. (Appendix A delineates the equations used.) This approach uses the following assumptions:

- One potency factor is valid for all exposure media (7.7)
- Exposure levels are constant for the duration of exposure
- An average human weighs 70 kg (150 lb); see Appendix A for formula used to derive average weights for infants and children
- For air exposure, the inhalation rate is 20 cubic meters per day for all age groups
- Nominal absorption rates are as follows (*Tetra Tech, 1985*):
  - -- Via lung: 0.3
  - -- Via skin: 0.03
  - -- Via GI tract: 0.5
- Contact rates with soils vary with age (*Schaum, 1984?*)
  - -- 0 to 1 year: 5 grams per day
  - -- 1 to 5 years: 10 grams per day
  - -- 5 to 70 years: 0.3 grams per day
- Exposure durations are media dependent: exposure via air occurs 24 hours per day, 365 days per year; exposure via soil occurs 6 months per year (24 hours per day), and exposure via drinking (ground) water is based on a consumption rate of 2 liters per day
- No depuration or degradation of PCB occurs (half-life is considered infinite)

The values delineated for adsorption rates are extracted from *Schaum (1984)*, which provides a risk assessment methodology for TCDD (dioxin) contaminated soil. Hence, there exists an implicit

assumption that these values are the same for PCBs. This approach is reasonable since these two chemicals are similar in terms of structure and some chemical properties; the main difference lies in their respective potency factors. The validity of this approach deserves questioning; nevertheless, it is justified to do so here because the same approach has been taken in at least two of the risk assessments upon which this case study is based (*Tetra Tech, 1985 and Henningson et al., 1988*).

(Note: These assumptions have been extracted from the literature; they collectively represent a conservative approach which is warranted on the grounds of insufficient data. While more complex analyses are possible, this case study is intended to illustrate how risk assessments have actually been conducted by professional entities of the environmental community; a critical look at this methodology is forthcoming in the "Results/ Discussion" section).

The equations in for calculating risk as depicted in Appendix A show how the risk values for PCB exposure from each medium are calculated and then added to arrive at a composite risk value. The risk calculations for air, groundwater, soil dermal contact, and fish ingestion routes assume a lifetime fraction of exposure duration, while using the standard adult body mass of 70 kg. The lifetime fractions for air and groundwater are set at 1 (which implies constant exposure every day for seventy years), whereas the fish ingestion lifetime fraction is set at 0.3, under the supposition that a "typical" individual consumes fish from waters near the site no more than three days out of ten. (These values would be considered very conservative, perhaps too conservative in the opinion of some individuals.)

Soil and food crop ingestion are assumed to have greater dependence on the age of the individual. Hence, cumulative intakes for three age groups (0-1 year, 1-5 years, and 5-70 years) are calculated, then used to determine the average daily intake and subsequent risk for each medium.

Absolute risk is defined as the risk associated with each exposure route. For each risk pathway, this absolute risk is then divided by the "background risk," which is a measure of risk from the same respective route but using background PCB concentrations. The quotient is termed "relative" risk, which serves as an indication of the increased risk from a given pathway due to the site contamination. To calculate consummate relative risk, the total absolute risk (sum of absolute risks from each pathway) is divided by the total background risk (sum of background risks from all pathways); it is not found by adding all the relative risks from each pathway (see Appendix A.)

Risk Assessment - Ecological This estimation is much more difficult than that for human risks, due to lack of data on intake rates, weights of organisms, etc. In addition, the dynamic interactions of an ecosystem are neither well understood nor readily quantifiable. Some models have been attempted at emulating relatively simple ecosystems (e.g. SWACOM), but they are not necessarily relevant to this case study, given the nature of the contaminant, the potential interactions between aquatic and terrestrial organisms, and contaminant transport phenomena.

Given these handicaps, an ecological risk assessment will be attempted in the following manner: First, the selected species will be addressed individually using acute and chronic effects data combined with media exposure levels to predict steady-state, long term reductions in populations/biomass. Then, where applicable, any further reductions due to indirect effects (i.e. damage to a given preceding trophic level) will be incorporated. While this approach doesn't take into account many parameters, it does provide a rough estimate of potential ecological damage and accounts for two of the most important factors: direct toxicity and the influences of predator-prey relationships.

The calculation used for direct effects is the quotient method as defined by *Barnthouse et al (1985)*. The toxicity data are compared with ambient PCB concentrations to estimate a

percentage reduction in population or biomass. The reductions from acute and chronic effects added together constitute the "direct" reduction in biomass; this direct reduction, coupled with the "indirect" reduction resulting from reductions in the availability of the preceding trophic level, comprise the total percentage reduction. (See Appendix A.)

In addition to treating each trophic level separately, an "overall" reduction for the aquatic ecosystem is calculated based on the EPA aquatic life criteria (*US EPA, 1984*). This approach is performed for comparison purposes only.

Cost Analysis

The cost analysis provides estimates of total costs to the waste generator for proper disposal and each of the following alternatives for remedial action due to improper disposal:

- No cleanup
- Remove soils contaminated with greater than 10 ppm PCB
- Remove soils contaminated with greater than 1 ppm PCB

The 10 ppm cleanup level is based on EPA guidelines for PCB spills which call for removal to 10 ppm when the spill occurs near human populations. This criterion has been used in determining remedial actions of some hazardous waste sites (*Henningson et al., 1988*). The 1 ppm cleanup level alternative is used for comparison purposes in order to assess whether further reduction is warranted and/or cost effective.

The total costs of theses alternatives are then compared to the total cost of proper (immediate) disposal, which has a relatively high initial cost but avoids all the ensuing regrets.

This cost analysis incorporates the following assumptions:

- Inflation rate is nominally 2 percent, and inflated interest rate is nominally 8 percent, resulting in a real interest

rate of 5.9 percent

- Contamination is discovered 5 years after disposal on the site
- Remedial investigation / feasibility study (RI/FS) costs are realized at the end of year 6
- Remedial costs are realized as a lump sum at the end of year 8
- Litigation costs are realized in years 8 - 10
- Unit costs for remedial operations are applicable for the range of contamination involved (i.e. no economies of scale)
- Unit costs are given in today's dollars

Table 16 summarizes the input parameters for the cost analysis. Table 17 depicts the timelines for the activities involved.

For proper disposal, there are two primary cost elements of interest: transportation and waste destruction. For improper disposal, these costs elements apply: remedial investigation / feasibility study (RI/FS), remediation, fines levied by the EPA, and costs of litigation for potential harm to human health and the environment.

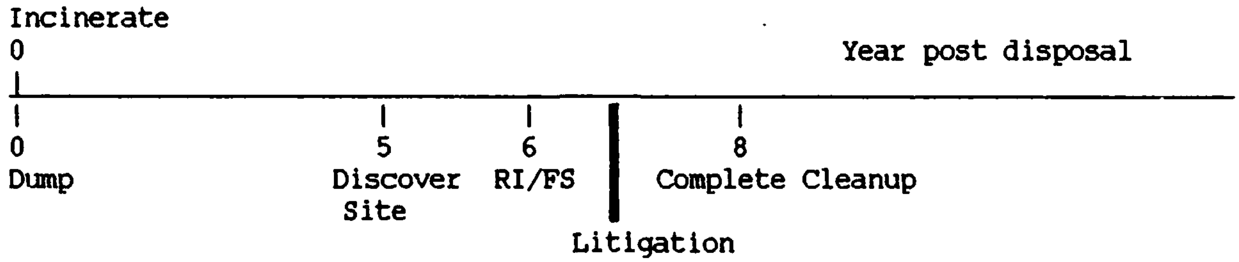
RI/FS Once the waste site is discovered, an RI/FS would be initiated to assess the extent and severity of contamination, as well as to evaluate alternatives for remedial action. As such, the level of activity during an RI/FS would be the same no matter which remedial action alternative is pursued. Therefore, the cost of the RI/FS is the same across the board and applies to all three alternatives for remediation after improper disposal.

In general, RI/FS costs vary considerably among sites. Rough estimates of these activities range from about $300,000 up to $10 million (*communication with Sally Martyn, US EPA - Region 10, 1989*). The size, complexity and extent of contamination of the site in this case study would call for an RI/FS with a cost tending towards the lower end of this range, because it is a rather small site with only one contaminant. Therefore, an overall RI/FS cost of $300,000 (today's dollars) is used. (For

TABLE 16. INPUTS FOR COST ANALYSIS

Item	Unit	Average Value	Range
Transportation of contaminated soil	$/ton-mi	0.5	0.3 - 0.8
Incineration	$/ton	350	300 - 500
Lawsuit - human	mil $	1	0.5 - 5
No. of cases		3	0 - 10
Lawsuit - environmental	mil $	2.0	0.1 - 8
No. of cases		1	---
Inflation rate		0.02	0.0 - 0.06
Inflated interest rate		0.08	0.04 - 0.10
Real interest rate		0.059	-0.02 - 0.10
CLEANUP COSTS			
Remedial Investigation/ Feasibilty Study	mil $	0.5	0.3 - 1.5
Remediation			
Transporation	$/ton-mile	0.5	0.3 - 0.8
Excavation & Backfill	$/ton	100.0	80 - 150
Treatment			
Incineration	$/ton	350.0	300 - 500
Overhead	% of sub-total	25.0	20 - 50
Contingency	% of sub-total	10.0	5 - 40

Table 17. TIME LINE OF ACTIVITIES



	Time (years after disposal)	
Milestone	Average	Range
Discovery of contamination	5	3 - 7
Site RI/FS		
Begin	5.5	4 - 8
Complete	6.0	4.5 - 9
Remediation		
Begin	6.5	5 - 10
Complete	7.5	6 - 12
Lawsuit Payments Realized		
Human Health	7.0	6 - 10
Environmental Compensation	8.0	7 - 12
Fines	6 - 7	4 - 9

both the RI/FS and remedial activity, it is assumed that the waste generator as the principal responsible party (PRP) bears all the costs of these actions. This may be the case in real situations, but it is also possible for the EPA to bear these costs initially and then sue the PRP for cost recovery.)

Remediation For comparison purposes, incineration is again the chosen method of treatment. (Other methods are possible at lower costs, but none of them will be considered here.) The subitems contributing to total remediation costs are excavation of contaminated soil and backfilling with "clean" soil (less than 10 ppm or 1 ppm soil, depending on the cleanup level), transportation of the contaminated soil to the incinerator, destruction of the waste material, overhead and contingency costs. Since the contaminated soil is removed from the site, and the residual PCB concentration is expected to remain adsorbed to the soil matrix, no leachate collection or gas venting system is needed (*Henningson et al., 1988*).

Fines Fines can range considerably depending on the situation and the responsiveness of the responsible party. CERCLA stipulates that the EPA can levy fines up to $25,000 per day if the regulatory action deems them appropriate (e.g. if the PRP is delaying the remedial process - *Stoll, circa 1987*). In one case, the EPA fined Chemical Waste Management, Inc. $2.5 million for improperly storing and diluting PCB wastes (*Chemical and Engineering News, 1985*). For this study, it is assumed that the EPA will levy a fine of $100,000 if the "No Cleanup" alternative is chosen. For the other two remedial alternatives, no fine is issued.

Litigation The risk estimates for human and ecological endpoints are incorporated into the cost analysis in the following manner. The risks to humans create potential costs of litigation. The calculated risk value is multiplied by both the assumed population exposed and the cost per litigation case to estimate a total cost of compensation for human carcinogenicity.

For costing purposes, it is assumed that the probability of litigation occurring is 1.

Ecological risks incorporated in a similar fashion. The main concern will be the potential effects on game fish (also referred to as "large fish" here) and overall ecological damage. For this study, the estimated reduction in game fish will be used to estimate "environmental compensation" that may result from litigation, and for which cleanup efforts alone are not sufficient.

Potential Benefits If the waste generator chooses to dispose of the PCB waste on its property, the money that would be spent on immediate destruction would be freed up for other use (before the other costs begin to be realized). It is assumed that this amount is placed in a "management reserve" fund and is invested in a certificate of deposit (CD) type account (i.e. interest earned is realized at maturity) until it matures at the five year point. This inclusion allows one to more fairly assess the economic advantages and disadvantages of each alternative.

The Bottom Line All costs and benefits are discounted to year 0 and summed accordingly. The alternative exhibiting the lowest net present cost would be considered by the waste generator to be the most desirable. (Note: The cost figures, as they appear in Tables 18-A, 18-B, and similar ones in Appendix B, are in then-year dollars (inflation = 2 percent). The net present values represent the sum of those figures once discounted to year zero (i_r = 5.9 percent).)

RESULTS

Human Health Risk Assessment The commensurate human risk of increased cancer associated with each alternative are summarized as follows (detailed results are in Tables B.1 through B.3 in Appendix B):

Alternative	Absolute Risk	Background Risk	Relative Risk
No cleanup/200 ppm soil	3.84E-02	1.14E-03	33.64
Clean to 10 ppm	3.07E-03	1.14E-03	2.69
Clean to 1 ppm	1.38E-03	1.14E-03	1.21

Figure 1 graphically depicts these results.

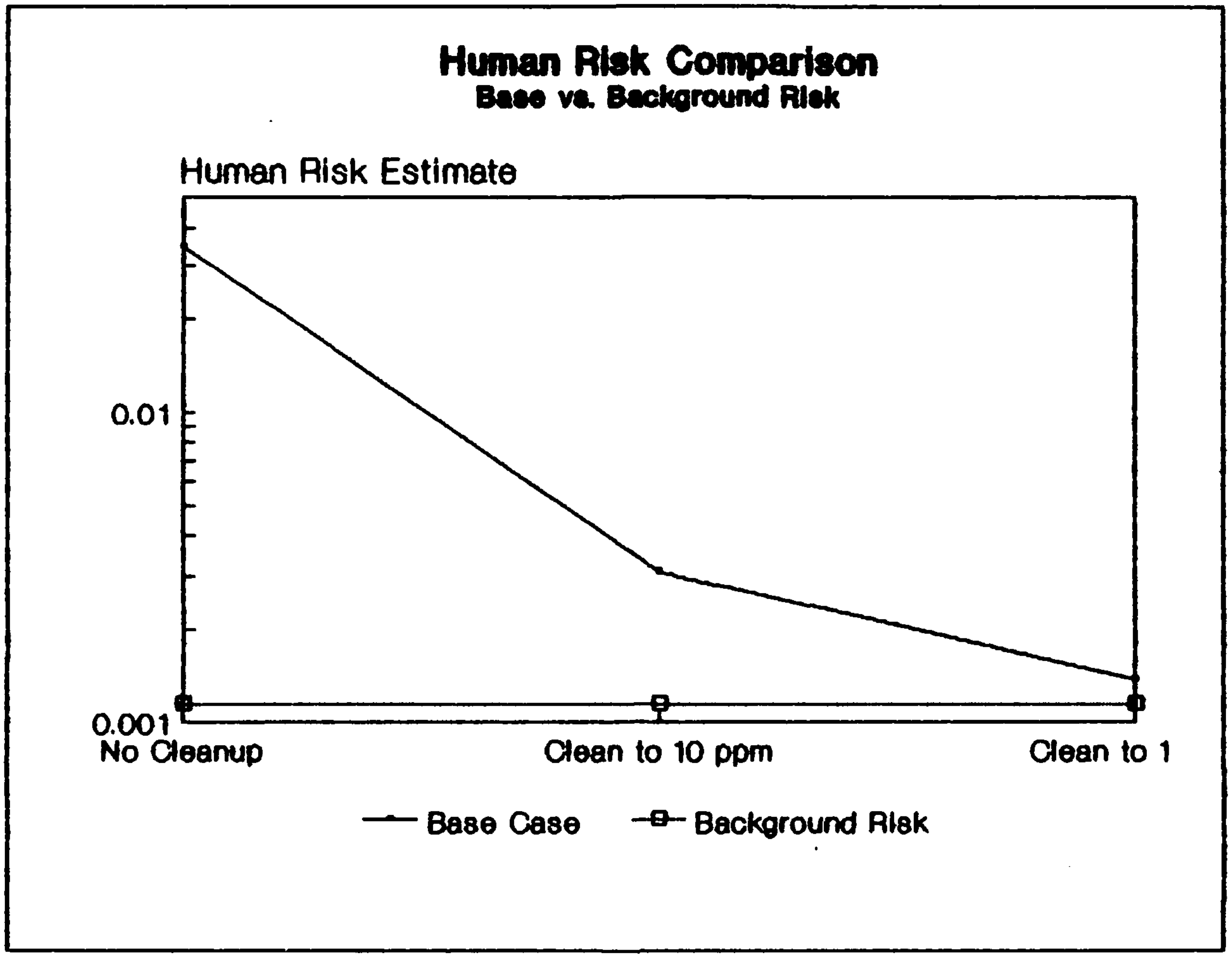
It appears that even the background risk is above the range considered acceptable (10^{-4} to 10^{-7}). This is because the fish ingestion route is driving the risks to much higher levels compared to the other routes. Without fish ingestion, the cumulative risks are as follows:

Alternative	Absolute Risk	Background Risk	Relative Risk
No cleanup/200 ppm soil	2.86E-02	2.00E-05	1430
Clean to 10 ppm	1.51E-03	2.00E-05	75.5
Clean to 1 ppm	2.10E-04	2.00E-05	10.5

As these tables and figure 2 indicate, the absolute risks are much lower without fish ingestion; the relative risks appear much greater, but the apparent effectiveness of cleanup actions also appear to be greater. In absolute terms, both remedial action alternatives are effective enough to reduced risks to acceptable levels, if fish ingestion is reduced or eliminated.

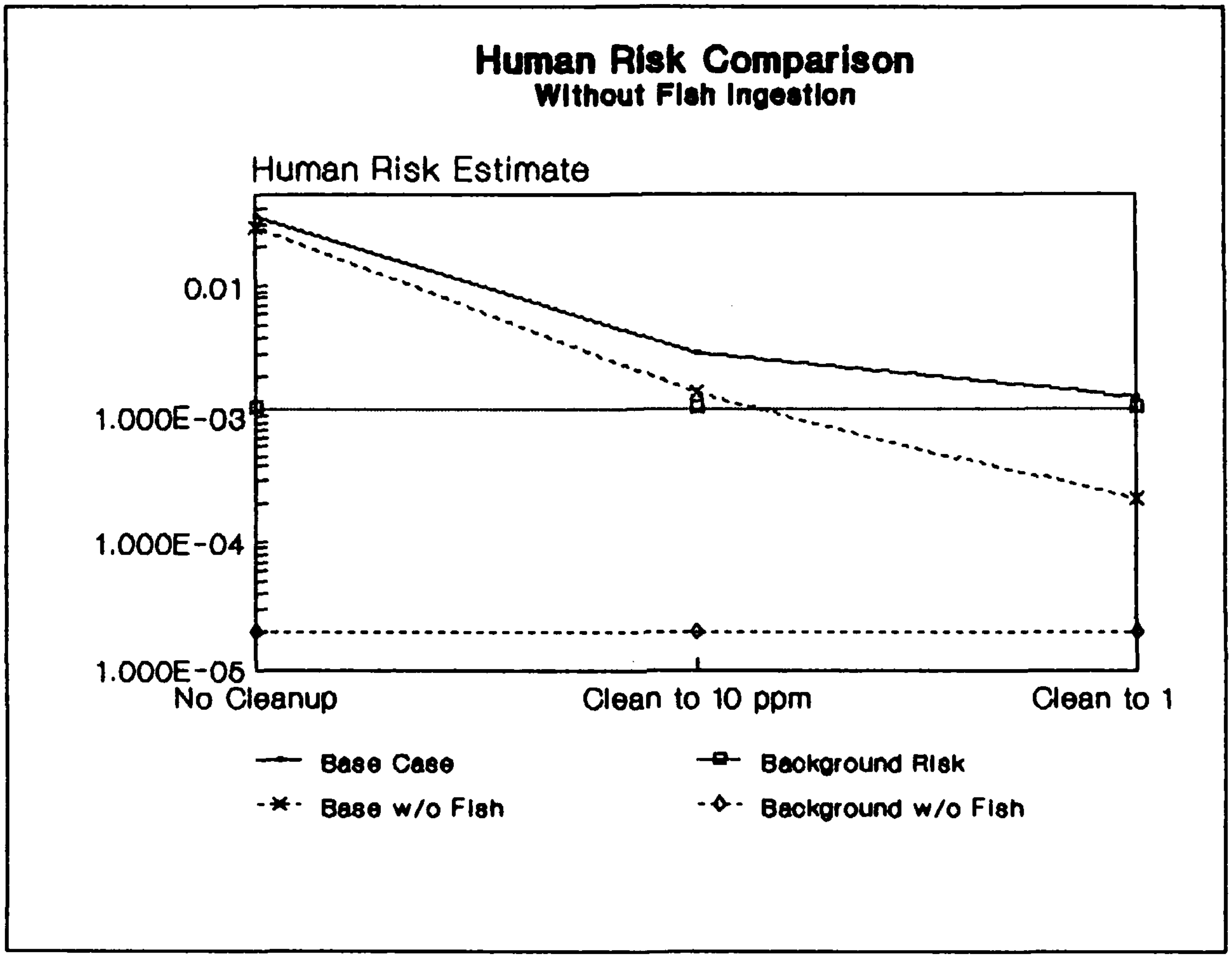
Ecological Risk Assessment The table below summarizes the results of the ecological risk assessment. The numbers are indications of expected long-term percent reductions in biomass for the organism categories of interest. The last line is the expected "macro" ecosystem biomass reduction based on the EPA

Figure 1.



Human Risk Comparison
Base vs. Background Risk
Human Risk Estimate
0.01
0.001
No Cleanup
Clean to 10 ppm
Clean to 1
Base Case
Background Risk

Figure 2.


Human Risk Comparison
Without Fish Ingestion
Human Risk Estimate
0.01
1.000E-03
1.000E-04
1.000E-05
No Cleanup
Clean to 10 ppm
Clean to 1
Base Case
Background Risk
Base w/o Fish
Background w/o Fish

aquatic life criteria of 2 micrograms per liter (acute) and 0.014 micrograms per liter (chronic), respectively (see Tables B.4 through B.6 in Appendix B).

	Percent Reduction in Biomass		
Organism	No Cleanup (200 ppm)	Clean to 10 ppm	Clean to 1 ppm
Terrestrial-Mink	3.125	0.156	0.016
Aquatic-large fish	0.227	0.011	0.001
Avian	0.527	0.312	0.302
Criteria-based	1.433	0.075	0.011

Based on this methodology, it appears that even without remediation the PCB contamination would have relatively little effect on ecological endpoints. This result bears similarity to other related findings (*Mayer et al., 1985 and Peakall, 1987*). Although this quotient method is rather crude (and unproven), it serves as a top-level indication of what may potentially occur.

Another approach would be to estimate the amount of PCB residual concentration in large game fish. If such concentrations were actually measured and found to be above the FDA's action level (2 ppm), the regulatory agency in conjunction with the EPA may ban fishing in the region. This ban would be of prime interest in the cost analysis, because it may become the driving factor for litigation of environmental damage claims. (Such a situation exists with the case of PCB contamination of the Hudson River. PCB levels in fish were found above the acceptable limit, leading to a ban on fishing which resulted in a $12 million lawsuit initiated by sportfishermen against General Electric Co., the responsible party - *New York Law Journal, 1987.*)

As an illustration, to estimate the residual concentration in large fish, two sources of exposure of concern are ambient water and the preceding trophic level (i.e. what the fish eats):

From Ambient Water

$$\text{Ambient Concentration} \times \text{Bioconcentration Factor} = 2.0\text{E-}06 \text{ mg/l} \times 4.2\text{E+}04 = 0.084 \text{ mg/kg}$$

+ From Food Chain

$$\text{Concentration in prey} \times \text{Feeding Rate} \times \text{Absorption Rate} \times \text{Duration} \times \frac{1}{\text{Body Weight}}$$

$$0.3 \text{ mg/kg} \times (0.05 \times \text{Body weight} = 0.15 \tfrac{\text{kg}}{\text{day}}) \times 0.7 \times 300 \text{ days} \times \frac{1}{3 \text{ kg}} = 3.15 \text{ mg/kg}$$

Total Intake

$$0.084 + 3.15 = 3.23 \text{ mg/kg } (= 3.23 \text{ ppm})$$

Although the actual concentration could vary considerably, this method serves as an indication that there may be a problem. It is interesting to note that the main concern in setting the FDA limit is human health, not the fish itself. In fact, many fish have been found to exist with no identifiable adverse effects even though the accumulated concentrations of PCBs in their systems are at levels which would be expected to cause harm (*Eisler, 1986*).

Cost Analysis Table 18-A details the costs for all four alternatives. (For convenience, proper disposal is referred to as "Option A," and the three alternatives under improper disposal are collectively called "Option B.") The net present cost is lowest for immediate disposal, followed by cleanup to 10 ppm, cleanup to 1 ppm, and no cleanup. These results illustrate part of what was discussed in the literature review: There exists a tradeoff between the expense of remedial action and costs associated with litigation. For the no cleanup alternative, litigation costs are expected to be highest. When remedial action is taken, the litigation costs drop substantially.

Also, the base case results indicate that the RI/FS cost alone would be significant enough to warrant proper disposal,

Table 18-A. COST ANALYSES — Base Case

Distance to burn facility: 500 miles

Unit Costs

Incineration (liquid)	350.0 $/ton
Incineration (solid)	500.0 $/cu yd
Transportation	0.50 $/cu yd-mile
Excavate & Backfill	100.0 $/cu yd

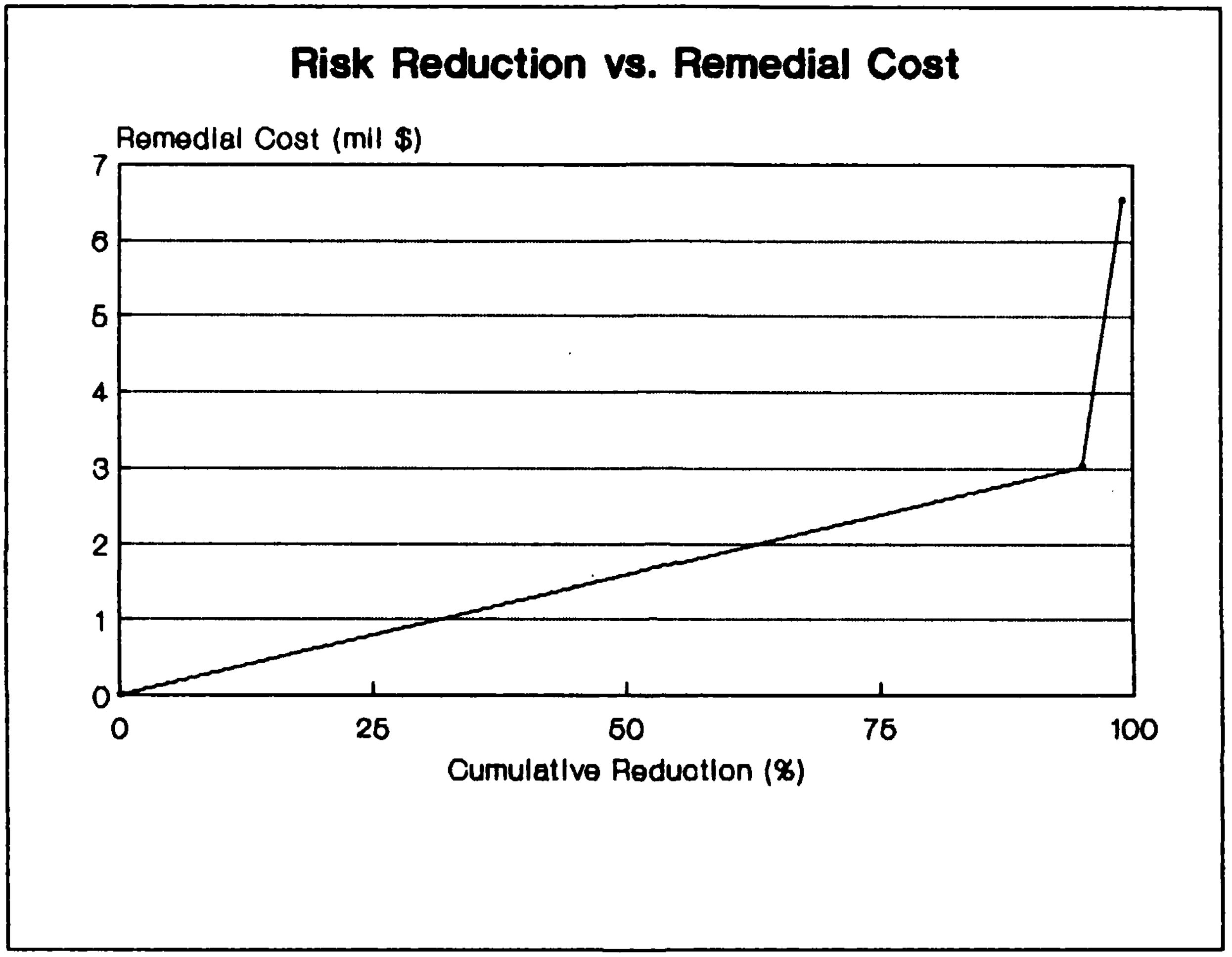
Interest rate: 0.080

Discount Factor: 1.059

ALTERNATIVES
(cost values are in million dollars)

Item	Year Cost Realized	OPTION A: Incinerate	OPTION B: No Cleanup	OPTION B: Cleanup to 10 ppm	OPTION B: Cleanup to 1 ppm
Quantity of Waste Material		10,000 gal		1666.000 cu yd	3600.000 cu yd
Immediate Destruction		0.030	N/A	N/A	N/A
RI/FS	6		0.423	0.423	0.423
Remediation	8	N/A	N/A		
Excavate & Backfill				0.263	0.569
Transportation				0.658	1.422
Incineration				1.316	2.844
Overhead				0.559	1.209
Contingency				0.224	0.483
Total Remdiatn	8	0.000	0.000	3.020	6.526
Fines	7	0.000	0.100	0.000	0.000
Human Health Litigation	7	0.000	8.587	0.686	0.308
Environmental Litigation	8	0.000	0.007	3.58E-04	3.58E-05
"Benefits" of Invested Capital	5	0.000	0.044	0.044	0.044
Net Present Cost		0.030	6.094	2.639	4.604

Figure 3.



Risk Reduction vs. Remedial Cost
Remedial Cost (mil $)
7
6
5
4
3
2
1
0
0
25
50
75
100
Cumulative Reduction (%)

because it is estimated to be over ten times greater than the cost for improper disposal. If RI/FS costs were significantly less, then the other cost elements would take on greater significance in terms of influencing the results and the decisionmaker's choice of disposal option. (Because of this outcome, the uncertainty analysis will include emphasis on the differences between the costs of the three alternatives for improper disposal, rather than just the differences between proper and improper disposal.)

10 ppm vs. 1 ppm Cleanup Figure 3 shows the cost required to achieve various risk reduction levels. It illustrates the fact that 95 percent of the expected risk reduction occurs with cleanup to 10 ppm, whereas the expense of remediation to 1 ppm is twice that of the 10 ppm cleanup. Referring back to table 18, the reduction in litigation cost for human health problems is relatively small when pursuing the more extensive remediation from 10 ppm to 1 ppm. This result is as expected since most of the risk reduction occurs with the 10 ppm cleanup. These results as a whole lead one to conclude that remediation to 1 ppm is not cost effective.

Human Health vs. Environmental Litigation In this case, it appears that the risks and litigation associated with human health far outweigh those for ecological damage. Although other methods may yield somewhat different results, the differences between the two are in line with expectations because of (1) the strong propensity of PCBs to remain adsorbed to soils, (2) studies which indicate PCBs pose little threat to various species despite the chemicals' persistence (*Mayer et al., 1985 and Peakall, 1987*), and (3) society's perception of the threats posed by hazardous waste contamination and the resulting high frequency of lawsuits against those responsible for creating such conditions (*Strelow, 1988*).

Modification of Approach - Incorporation of Chance Outcomes)

This analysis assumes that the waste generator is positively identified as the responsible party, and as such will bear all

ensuing regrets of improper disposal. In actuality, there exists a finite chance that the responsible party would not be identified. The likelihood of this occurring could vary from virtually nil all the way to near one, depending on the location and distribution of contamination, the ability of the waste generator to cover his tracks, etc. For illustrative purposes, the following shows how the results would change if the assumed chance of getting caught is less than one. It will also consider another factor: the waste generator may not at least initially pay for the RI/FS and remediation; instead, the EPA or state government may fund these efforts, and then sue the waste generator for cost recovery.

Given that the improper disposal takes place on the waste generator's property in a growing suburban/residential area, let's assume for this exercise the following:

Probability of getting caught = 0.75

Probability of cost recovery given that the waste generator gets caught = 0.75

$$\text{Probability of paying} = \left[\text{Prob. of getting caught}\right] \times \left[\text{Prob. of cost recovery}\right]$$

$$= 0.75 \times 0.75 = 0.56$$

This factor is applied to the RI/FS and remediation cost elements for the base case; the probability of getting caught (0.75) alone is applied to fines. None of these factors are considered in the litigation and "benefits" cost elements.

Table 18-B shows the effect on the results. The total costs are lower for the improper disposal alternatives, but still greater than immediate disposal. What value(s) of the probability of payment would have to be used to make the combined RI/FS and remediation cost virtually on the same level as proper disposal? This question is answered below.

Let p = Probability of paying for RI/FS and Remediation

Table 18-B. COST ANALYSES — Base Case with Added Chance Outcomes

Distance to burn facility: 500 miles

Unit Costs

Incineration (liquid)	350.0 $/ton
Incineration (solid)	500.0 $/cu yd
Transportation	0.50 $/cu yd-mile
Excavate & Backfill	100.0 $/cu yd

Interest rate	0.080
Discount Factor	1.059

ALTERNATIVES
(cost values are in million dollars)

Item	Year Cost Realized	OPTION A	OPTION B		
		Incinerate	No Cleanup	Cleanup to 10 ppm	Cleanup to 1 ppm
Quantity of Waste Material		10,000 gal		1666.000 cu yd	3600.000 cu yd
Immediate Destruction		0.030	N/A	N/A	N/A
RI/FS	6		0.237	0.237	0.237
Remediation	8	N/A	N/A		
Excavate & Backfill				0.263	0.569
Transportation				0.658	1.422
Incineration				1.316	2.844
Overhead				0.559	1.209
Contingency				0.224	0.483
Total Remdiatn	8	0.000	0.000	1.691	3.655
Fines	7	0.000	0.100	0.000	0.000
Human Health Litigation	7	0.000	8.587	0.686	0.308
Environmental Litigation	8	0.000	0.007	3.58E-04	3.58E-05
"Benefits" of Invested Capital	5	0.000	0.044	0.044	0.044
Net Present Cost		0.030	5.962	1.665	2.655

Cost of proper disposal = (Cost of RI/FS + Cost of Remediation) x P (or fines for No Cleanup)

(Note: Cost figures have been discounted to year zero; values are in million dollars)

No Cleanup

$$0.030 = (0.3 + 0.067) \times P \longrightarrow P = 0.082$$

Cleanup to 10 ppm

$$0.030 = (0.3 + 1.91) \times P \longrightarrow P = 0.014$$

Cleanup to 1 ppm

$$0.030 = (0.3 + 4.12) \times P \longrightarrow P = 0.0068$$

This example shows that according to expected value theory, the probability of paying for RI/FS and remediation, based on the chances of being caught and being sued for cost recovery, has to be quite small in order to make improper disposal appear cost effective (whether these values found here are commensurate with reality is unknown). The rest of the results and the uncertainty analysis does not take into account these probabilities.

Summary of Results The results of this case study indicate that the total cost of improper disposal may be far greater than proper disposal. When considering only the former, three plausible alternative actions (in order of decreasing costs) are No Cleanup, Clean up to 1 ppm PCB soil, and cleanup to 10 ppm soil. For no cleanup, the driving factor is the cost of litigation which is based on a human health risk assessment that estimates the increased incidence of human cancers in the population exposed. For cleanup to 1 ppm, the human and ecological risks and ensuing litigation costs are reduced further, but the cost of remediation is substantially higher, making a 10 ppm cleanup the most cost effective alternative.

DISCUSSION

Limitations and Deficiencies of Human Risk Assessment

The risk assessment methodology is rather simplistic and as such relies on several assumptions (both explicit and implicit) which limit the validity of the results. Those defending this methodology claim that the assumptions are necessary due to a lack of sufficient knowledge and data which can be translated into appropriate mathematical relationships and values for relevant parameters. Due to these deficiencies, assumptions are made to ensure that errors will result on the conservative side (i.e. the risks will be overestimated instead of underestimated). The problem created with this approach is that the effect of conglomerating many conservative assumptions leads to risk estimates for conditions which may have extremely low probability of actually occurring (*Maxim, 1989*). In fact, *Maxim (1989)* explicitly addressed the risk assessment in the Strandley Scrap Metal/Manning RI/FS (which Tetra Tech performed), which was used in developing this case study. *Maxim (1989)* specifically called out the following:

- Tetra Tech used a 2000 ppm PCB soil concentration when this level was actually found in only one "hot spot;" over 90 percent of the PCB concentration in the soil was 100 ppm or less
- PCBs were assumed to be infinitely persistent (no degradation) whereas their half-life in soil is actually on the order of 2 years; thus exposure levels would decrease with time instead of remaining constant
- Tetra Tech used absorption rates of 1 for soil ingestion even though the document upon which the risk assessment was based (*Schaum 1984*) recommended much lower values (0.2 - 0.5)
- Assumed soil ingestion rates were perhaps the highest ever

reported; actual rates are one to two orders of magnitude lower

Maxim (1989) reports that the combination of these conservative assumptions led to a lifetime risk estimate that is eight orders of magnitude higher than the estimate which relies on less conservative values and assumptions. The case study in this report approaches the less conservative range by using lower absorption and ingestion rates, as well as lower soil PCB concentrations. However, the degradation of PCBs over time is not considered here.

Potency Factor As mentioned previously, the assumed potency factor (7.7 $(mg/kg/day)^{-1}$) is based on the highest slope of an experimentally-derived dose-response curve (Henningson et al., 1988). Some risk assessments have used a lower value of 4.34, which is based on results of earlier studies; an EPA employee recommended the higher value because it is considered to be more current (*communication with Dana Davoli - EPA Region 10, 1989*). The use of a single value (as opposed to a range of values) for the potency factor implicitly assumes a linear dose-response relationship, when in fact it is typically concave curvilinear; hence the potency factor should be lower at lower doses; using a single value overestimates the risk (*Maxim, 1989*).

Exposure Duration and Contact Rates Air, groundwater, and fish ingestion are assumed to occur every day over a seventy year lifetime. This assumption obviously leads to overestimates of risk from these routes. A person would have to stay very close to the site for most of his or her life to approach these exposure levels. For fish ingestion, even if someone actually ingested fish up to 30 percent of the time, much of it is likely to come from sources other than waters contaminated by the PCB site. (PCB levels in fish from other sites may be higher or lower than those considered here.)

For soil ingestion, each age group of exposure is assumed to come in contact with soil every day six months out of a year. A typical individual is indoors for longer periods relative to being

outdoors; combined with environmental conditions which may inhibit contact (e.g. precipitation), actual exposures are likely to be lower than those assumed in the risk assessment. Those who never come near the site are likely to experience near zero exposure.

At least two of the risk assessments used for this case study (*US EPA (1988b) and Tetra Tech, 1985*) point out the irony that the greatest exposure may occur during and as a result of remedial activities. The laborers would face the greatest risks (if not properly attired); in addition, various construction equipment could cause an increase of airborne particles contaminated with PCBs. Under dry, somewhat windy conditions, the soil particles would be transported to nearby human targets, thus increasing exposure levels. However, those levels would be of short duration (less than one year). Precipitation would remove the particulate matter from the airborne phase, reducing exposure levels even further.

The Human Element The risk assessment methodology assumes average adult weight of 70 kg. This value is based on statistics for male populations. In addition, the methodology assumes the same absorption (metabolic) rates, contact rates, and lifetime span for everyone exposed (with the exceptions of soil and food crop ingestion). In reality, many differences exist among individuals. While they would be difficult to fully account for in a risk assessment, one needs to be aware of this caveat. Some individuals may be more sensitive to exposure (babies, small children), while others may be less susceptible to contracting illness from PCB exposure.

PCBs and Other Carcinogenic Substances The risk assessment looks only at the expected increased incidence of contracting cancer via PCB exposure from the contaminated site. A 1/1000 increase may seem substantial at first glance, but it is small compared to the one in four cancer contraction rate that has been determined statistically (*Paustenbauch, 1989*). A typical individual is exposed to many potentially carcinogenic substances, through foods, air, indoor pollution, etc. Indeed, little is known if the combined effects of these absorbed chemicals are additive, synergistic, or antagonistic.

For PCBs alone, one study suggests that they may in fact prevent cancer at low exposures instead of promote the disease (*Hayes, 1987*). Moreover, there has yet to be any epidemiological evidence showing that PCBs do in fact cancer. *Stehr-Green et al. (1986b)* reported that no statistically significant increase in cancer or any other adverse effect could be found in individuals (sportfishermen in particular) who had significantly higher levels of PCBs in their blood serum and adipose tissue. On the other hand, no studies have proven that PCBs do not cause cancer either. We may never know the answer for sure.

Ecological Risk Assessment

The results in this case study indicate that PCBs are likely to have little effect on several species populations and the ecosystem as a whole. Even though some evidence exists to support this finding (*Peakall, 1987, Mayer et al., 1985 and Mahanty, 1987*), one must bear in mind that many factors have been ignored in this scenario, including the vast number of species in virtually every ecosystem and their wide range of susceptibilities to PCBs, along with the dynamic interactions between those species. For avian species, at least two documents appear to conflict in terms of their reported effects on birds. *Eisler (1986)* indicates that at rather high exposure levels (2000 - 6000 mg/kg diet), birds are likely to experience a number of effects including morbidity, tremors, and muscular incoordination. On the other hand, *Peakall (1986)* found little harm to birds (with dose levels ranging from 100 ppm to 5000 ppm). Although both report that PCBs do bioaccumulate in many species of birds, they seem to diverge on the significance of this phenomenon.

Likewise, *Mayer et al (1985)* reported that PCBs pose little threat to rainbow trout. Their study concluded that the harm that was reported (at 3 micrograms per liter or above) was probably due to the petroleum hydrocarbons (in transformer oil) in which the PCBs were a constituent, rather than the PCBs themselves.

Regardless of these and other findings, those investigating ecological effects of PCBs would agree on one statement: there

simply is not sufficient data to confidently conclude one way or another on whether or not PCBs are harmful to ecosystems in general. As such, the EPA's criteria tend to be conservative. It is interesting to note the method with which the chronic toxicity criterion of 0.014 micrograms per liter (24 hour average) is derived: The chronic effects level for mink (0.64 mg/kg diet) is divided by the geometric mean bioconcentration factor for salmonids (45000) to arrive at 1.4E-05 mg/l (*US EPA, 1980*). The accuracy of such a criterion is suspect at best.

Validity of Expected Value Theory

The method of calculating human health litigation relies on an expected value approach whereby the increased cancer risk is multiplied by the number of individuals exposed and by an assumed cost of compensation due to lawsuit award or settlement. (The approach is similar for determining environmental litigation costs.) This approach may be sufficient for cost comparison purposes, but shouldn't be relied on too heavily. For instance, if a decisionmaker for the waste generator was trying to decide if and how much money should be set aside to cover litigation costs, he might be presented with these possibilities:

Scenario	Probability of Occurrence	Cost of Litigation	Expected Value
Low risk, high regrets	0.10	$3,000,000	$300,000
Medium risk & litigation	0.50	$600,000	$300,000
High risk but low regrets	0.90	$333,333	$300,000

All three scenarios would lead to the same conclusion: Reserve $300,000 for compensation. Yet in the first two cases, the responsible party would be substantially underfunded. In this simple

situation, either litigation award would occur, or it would not (probability = 0 or 1); as such the company should set aside $3,000,-000 to be fully covered.

Of course, there exists a finite probability that no litigation would ensue. What are the opportunity costs of earmarking several million dollars for compensation? The answer depends on a company's financial health and goals. If the money is invested in relatively liquid securities, the regrets are likely to be small. However, if the company needs the assets for capital investment, then the regrets could be more significant if such investment leads to strengthening the company's financial condition.

The bottom line is that expected value calculations should be viewed critically. It is better to separate the probabilities from the costs and allow the decisionmaker to choose which scenario he prefers.

Value Sets of Decisionmakers

There are basically two categories of decisionmakers to consider: Those that would be most concerned about the magnitudes of regrets (costs), and those that are most influenced by the likelihood of bearing the cost burdens of regrets. Because of the relative costs of improper disposal are much greater than those for improper disposal in this case, the results would most easily influence the former class of decisionmaker to choose proper disposal. However, since this analysis doesn't fully consider other realistic scenarios that depend on chances of detection, the latter type of decisionmaker is less likely to be influenced by the results contained herein. In other words, unless one could persuade the latter decisionmaker that the probability of getting caught is extremely high, he is likely to choose improper disposal, thus favoring short term in gains in spite of the possibility of large regrets.

Risk Assessment Data as Legal Evidence

Risk assessments have been used primarily to estimate potential damage mostly to human health and to some degree to ecosystems, thereby providing a quantitative means to determine environmental standards, to prioritize environmental problems, and to decide on remedial actions. However, some civil actions have attempted use risk assessment data as evidence in toxic tort cases (*Landau & O'Riordan, 1988-89*). In some cases, the evidence was deemed inadmissable; in others, such evidence was considered irrelevant (*Brown vs. Southeast Pennsylvania Transit Authority - Landau & O'Riordan, 1988-89*). There are many factors which have influenced those decisions on admissability, including the present condition of the plaintiffs, the jurisdiction in which the case is heard, etc. Overall, it appears that plaintiffs have had difficulties in getting such information into the courtroom; but while the odds favor the defendants (industry), there still is a significant, reasonable chance that such data could be used, leading to an award for the plaintiff.

Many industries/corporate entities have accepted the risks of facing civil action in order to save near term monetary resources. The probabilities may be in their favor (albeit not overwhelmingly), but the regrets certainly are not so. Indeed, the general arena of toxic tort cases is in a very dynamic state of flux at present. Many more environmentally-related lawsuits are reaching court dockets, and there is wide disparity in the rulings handed down. Recently a precedent may have been set in the case of *Potter vs. Firestone Tire and Rubber Co. (Monterey Superior Court No. 81723)*. The plaintiffs were awarded $3.9 million ($2.6 million in punitive damages) as compensation for fear of increased risk of cancer (*Echenique, 1988*). The key statement was the ruling that "... enhanced susceptibility to cancer or other life threatening diseases is a 'presently existing physical condition.'" In most other cases, plaintiffs had to demonstrate that actual manifestations of physical harm exist before compensation for increased risk of contracting future health problems were allowed (*Cummings, 1987-88*). Whether other courts will rule in

a manner similar to *Potter vs. Firestone* remains uncertain for now.

The reasons for reluctance to consider risk assessments as evidence in toxic tort cases lie in the traditional approaches to determining liability in such cases. Basically, the plaintiff had to show physical manifestation of harm as well as show with reasonable certainty or probability that the defendant was responsible (*Cummings, 1987-88*). Two types of arguments that could be used are "but for" and "substantial factor." (*Foster, 1988*) "But for" means that the plaintiff under the same conditions in which he or she has existed would not have contracted disease or other adverse effects "but for" the actions on the part of the defendant. The other argument generally stipulates the defendant was a "substantial factor" (contributing to more than half) in the causation of the plaintiff's ailment (*Foster, 1988*). These arguments tend to break down in toxic torts, because of the difficulties in proving a link exists between the defendant's actions and the plaintiff's illness, along with the fact that a latency period often exists between exposure and disease manifestation (*Forstrom, 1987*).

With latency period a significant factor, the establishment of when the statute of limitations begins becomes very important. Should it start when contamination first takes place, when the exposure starts, or when the disease becomes evident? To solve this dilemma, 39 states have adopted the "discovery rule," whereby the statute of limitations begins at the time when the plaintiff "knew or should have known" of possible injurious exposure (*Cummings, 1987-88*). Although still open to interpretation, this ruling narrows the possibilities and favors the plaintiff.

reatest concern over accepting and relying upon risk assessment data for determining probable cause is the chance that defendants could be forced to pay when no injury will actually occur, i.e. courts do not want to open the floodgates to speculative claims (*Robinson, 1985*). However, those gates may already be opening. In addition to the precedents mentioned above, some states have adopted rulings/legislation which greatly favor the plaintiff. In 1987,

California adopted Proposition 65 which established the possibility of large fines and even "bounties" against unlawful polluters. Moreover, it shifted the burden of proof from the plaintiff to the defendant. The latter now has to prove that its actions were not the cause of the plaintiff's ailment (*Scroggin, 1987*). In Oregon, the law states that "... a person who has the care, custody, or control of hazardous waste is strictly liable for any personal injury or property damage that results from improper disposal of that waste." Only California, New Jersey, and Minnesota have similar statutes (*Landau & O'Riordan, 1988-89*).

Natural Resource Claims (*Habricht II, 1987*) CERCLA/SARA legislation contains provisions for governmental entities to sue polluters for natural resource damages caused by the defendant's improper disposal practices. The damage awards are limited to amounts needed to "restore, replace, or acquire the equivalent thereof," and only to those residual damages beyond which the remedial actions cannot repair. In addition, these damages apply only to "public" natural resources (although the definition of what constitutes a public natural resource is somewhat open to interpretation). Up to now, most lawsuits of this kind have been initiated at the state level, with few at the federal or municipal level. One exception is the case of *the United States vs. AVX Corporation (No. 83-3882-Y, Massachusetts)*, wherein a claim of $50 million was filed against the companies responsible for PCB contamination of New Bedford Harbor.

CERCLA stipulates that private persons may not sue for any such natural resource damages. However, in at least one case a judge allowed such a claim to go to trial. As mentioned earlier in the report, a group of commercial fishermen sued General Electric Co. for PCB contamination of the Hudson River and the subsequent ban on fishing for striped bass (*New York Law Journal, 1987*). (The author does not know if a ruling has been handed down as yet.) GE already had paid $4 million as part of a settlement with New York state in 1976 (*New York Law Journal, 1987*).

Perceived vs. True Risks

The risk assessment data in and of itself does not convert directly to a probability of lawsuits occurring. Rather, assuming they are admissable as evidence in a toxic tort, they can be translated into a probability of losing the lawsuit (i.e. they serve as an indication of the weight of evidence against the defendant) and thus help determine the magnitude of claims awards. The likelihood of civil action being initiated would depend (at least in this case) on the perceived risk on the part of the individuals living near the site. This perceived risk will be a function primarily of two factors: the suddenly rising incidence of unusual health problems (if any), and the discovery of the site and the publicity resulting from the discovery. Even if the true risks to humans are small, there is a very strong chance that at least a portion of the population in the vicinity would initiate civil action even if no health effects have become manifest. Once civil actions begin, the decision in favor of the plaintiffs or defendant will depend to varying degrees on epidemiological evidence (for the site or historical sites similar to the one at hand), risk assessment data (similar to that described in the case study), and the presence or absence of present physical conditions which may be linked to the site contamination. For this scenario, the analysis takes a conservative approach by assuming that civil action will definitely occur (P = 1). The results of risk assessment factor into the jury award or settlement as described previously.

Data Quality/Validity

The confidence placed in the risk and cost analyses depend in part on the valid .y of the data available in the literature. Given the manner in which these data are presented (values were scattered; few if any values were presented in a statistical format), it is difficult to say how accurate the results are. Much of the data are subject to wide variations in reported values, in particular the levels of PCB concentrations causing detrimental effects in various

organisms, the PCB concentrations in various media due to contamination and environmental dispersion and diffusion, and the various site parameters which contribute to the spread of contamination. Remediation and litigation costs may also vary considerably, depending on the site conditions, the actual number of people exposed, the weight of evidence supporting the claim(s) of health damage due to contamination, etc. With such wide ranges of values for many influencing factors, many combinations of values are possible which could alter the estimates of total costs for the disposal / remediation alternatives considered. However, as the uncertainty analysis will show, it appears that under most reasonable conditions, proper disposal remains economically favorable to improper disposal.

Other Scenarios

Apart from the uncertainty analysis, there exists at least one set of plausible (but unlikely) conditions under which improper disposal appears more cost effective:

- Contamination is spread over a wider area and/or not on the waste generator's property
- The site is not discovered or cannot be traced to the waste generator
- The RI/FS and remediation costs are borne by the government which is unable to successfully recover those costs
- No litigation costs ensue

In the case study, it is assumed that only one contaminant (PCBs) exists at the site, which resides on property owned by the entity. Although this situation is rare (sites usually have more than one type of waste stream), it is by no means completely unheard of. Given these conditions, it is more likely than not that the responsibility would be traced to the waste generator. Such likelihood may be reduced if the waste were either dispersed over a much larger region that is not owned by the entity, or if the waste oil were

dumped at a site which contained other chemicals from other generators, such that it would be difficult if not impossible to identify this particular responsible party. (But these situations would give rise to the possibility of someone either internal or external to the company reporting such illegal actions to the appropriate authorities.)

UNCERTAINTY ANALYSIS

Given that much of the data used in this case study are subject to large variations under actual conditions, it is warranted to explore the ranges of values of at least some of the parameters to support the findings of the base case. This section will consider five sets of conditions and values which are different from those previously used. The first two try to emulate conditions which would tend to make improper disposal appear more cost effective.

Uncertainty Case 1: Low Range of Human Health Risk

To develop the low end of the range of human risk and to see the effect on total costs, the following parameter values are changed as shown below:

Parameter	Base Case	Uncertainty Case 1
Air Inhalation		
Absorption rate	0.3	0.25
Duration (lifetime fraction)	1.0	0.5
Groundwater		
Absorption rate	1.0	0.5
Duration (lifetime fraction)	1.0	0.5
Soil - Dermal Absorption		
Absorption rate	0.03	0.01
Lifetime fraction	0.5	0.3
Soil Ingestion		
Contact rates (g/day)		
0 - 1 years	5.0	0.05
1 - 5 years	10.0	0.10
5 - 70 years	0.3	0.03
Absorption rates - all age groups	0.5	0.2
Exposure durations	0.5 x age group interval	0.25 x age group interval

Food Crop Ingestion		
Absorption rates (all age groups)	0.3	0.2
Exposure durations	same as for soil ingestion	
Fish Ingestion		
Contact rate (g/day)	454.0	6.5
Absorption rate	0.75	0.5
Duration (lifetime fraction)	0.3	0.04
Cancer Potency Factor ($(mg/kg/day)^{-1}$)	7.7	4.34

Results - Case 1 Figures 4 and 5 show the risk estimates and total costs, respectively, of the base case compared to uncertainty case 1. Primarily due to substantially lower fish ingestion, the risks are about one to two orders of magnitude lower than in the base case. The cost of the No-cleanup alternative is much less due to reduced human health litigation; but it is still one order of magnitude greater than immediate disposal. The total costs of remediation to 10 ppm and 1 ppm, respectively, are reduced only slightly because remediation costs are their respective cost drivers and are the same as those for the base case. Hence, for improper disposal, no cleanup is the most cost effective alternative under these conditions (Also see Tables B.7 through B.10 in Appendix B.)

Uncertainty Case 2.1: Lower Costs Combined with Low Human Risk

The values associated with the low estimate of human health risk are combined with lower unit costs, longer timelines for activities involved (RI/FS, remediation, etc.), and a higher real interest rate in an attempt to make improper disposal appear more favorable. The values used here are as follows:

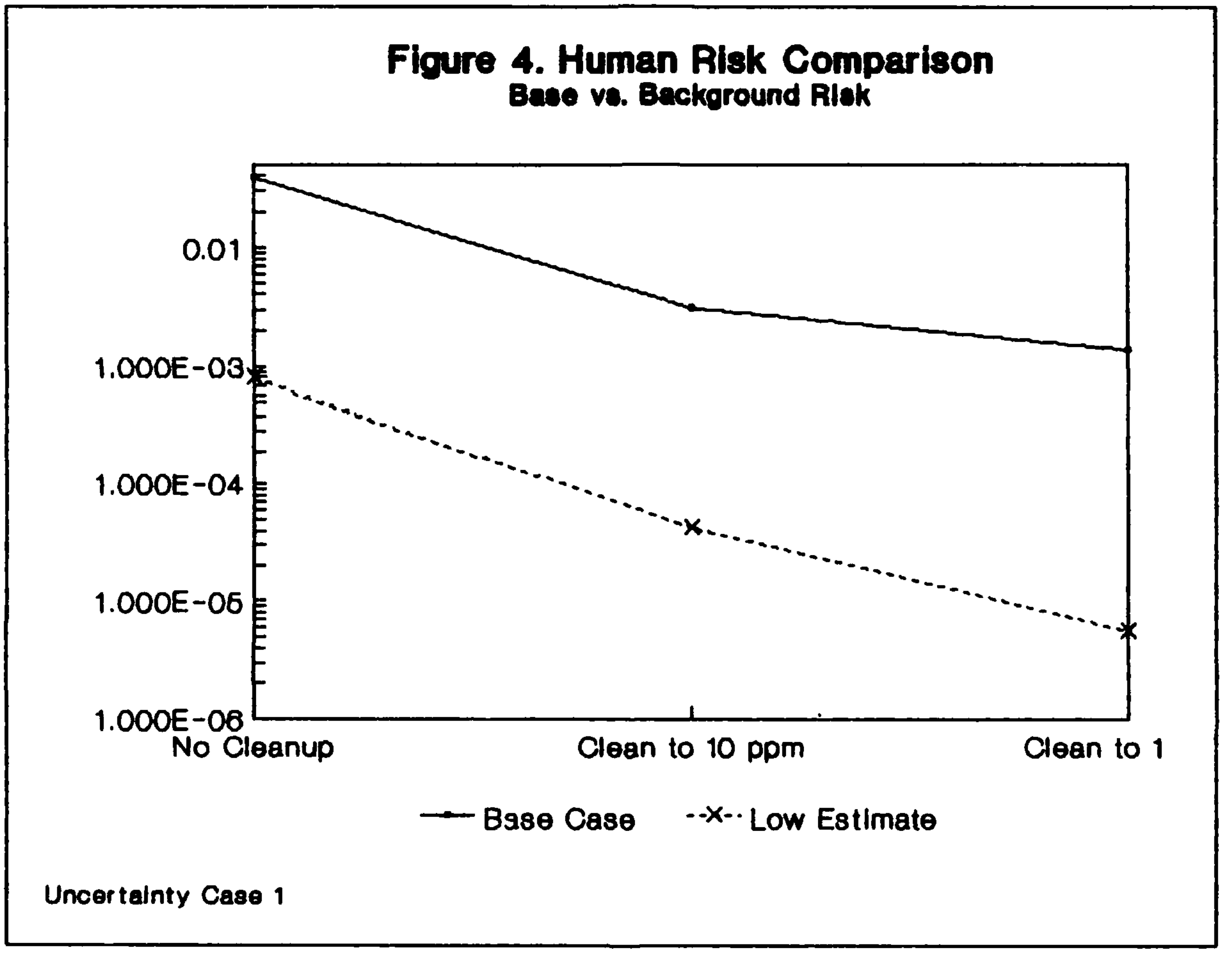


Figure 4. Human Risk Comparison
Base vs. Background Risk
0.01
1.000E-03
1.000E-04
1.000E-05
1.000E-06
No Cleanup
Clean to 10 ppm
Clean to 1
Base Case
Low Estimate
Uncertainty Case 1

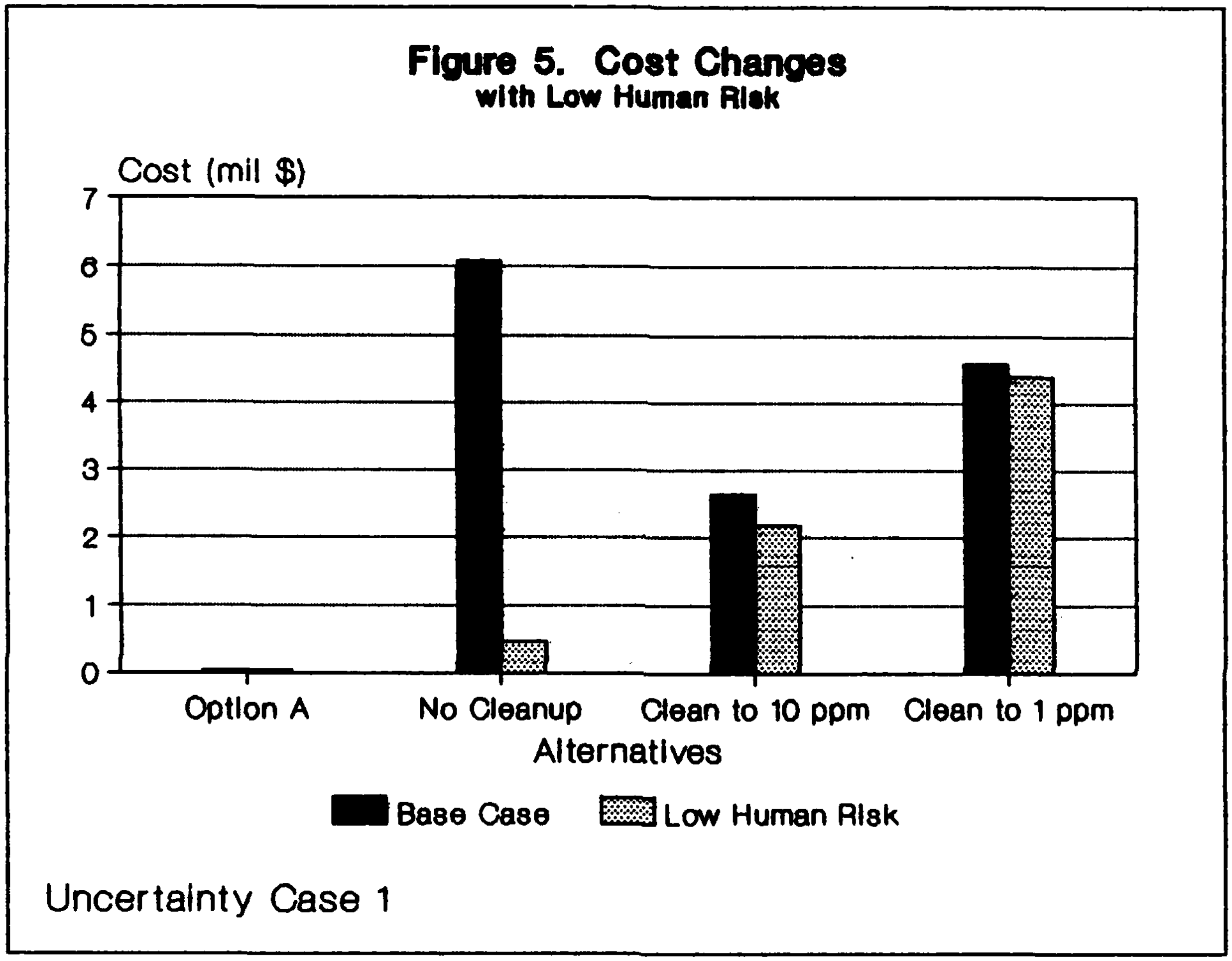


Figure 5. Cost Changes
with Low Human Risk
Cost (mil $)
7
6
5
4
3
2
1
0
Option A
No Cleanup
Clean to 10 ppm
Clean to 1 ppm
Alternatives
Base Case
Low Human Risk
Uncertainty Case 1

Parameter	Base Case	Uncertainty Case 2.1
Human Health Risk	see Uncertainty Case 1	
Volume of Soil Excavated (cubic yards)		
Cleanup to 10 ppm	1666	500
Cleanup to 1 ppm	3600	1000
Unit Costs		
Incineration - liquid ($/ton)	350	250
Incineration - solid ($/cu yd)	500	375
Transportation ($/cu yd-mile)	0.5	0.25
Excavation & Backfill ($/cu yd)	100	80
RI/FS (million $)	0.3	0.1
Interest rate (%)	8	10
Inflation rate (%)	2	0
Real interest rate	5.9	10
Timelines (year cost realized)		
RI/FS	6	9
Remediation	8	11
Fines	7	9
Human Health Litigation	7	15
Environmental Litigation	8	12

Results - Case 2.1 Figure 6 (and Table B.11 in Appendix B) show the resultant lower costs with these values. Costs are substantially lower for all alternatives, but immediate disposal is still lowest by at least one order of magnitude. For improper disposal, no cleanup is the cheapest, although the differences are not as great as in uncertainty case 1.

Uncertainty Case 2.2: Low Costs with Base Risk

The base case values of factors for human risk were combined with the values for cost factors in uncertainty case 2.1 to isolate the effects of the lower cost factors. As figure 7 shows, the results are as one should expect: Total costs for all alternatives are higher than for uncertainty case 2.1, but lower than those in the

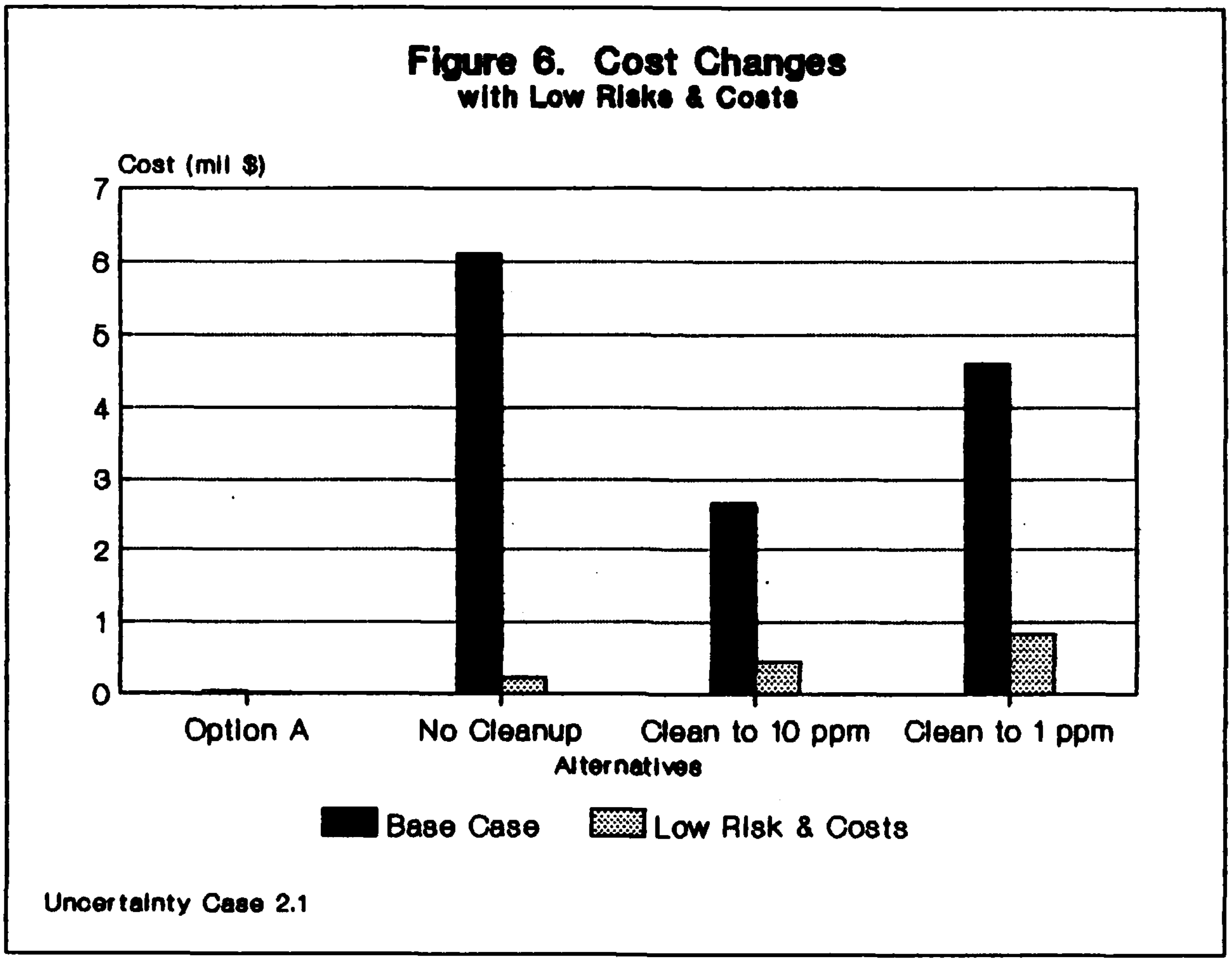


Figure 6. Cost Changes
with Low Risks & Costs
Cost (mil $)
7
6
5
4
3
2
1
0
Option A
No Cleanup
Clean to 10 ppm
Clean to 1 ppm
Alternatives
Base Case
Low Risk & Costs
Uncertainty Case 2.1

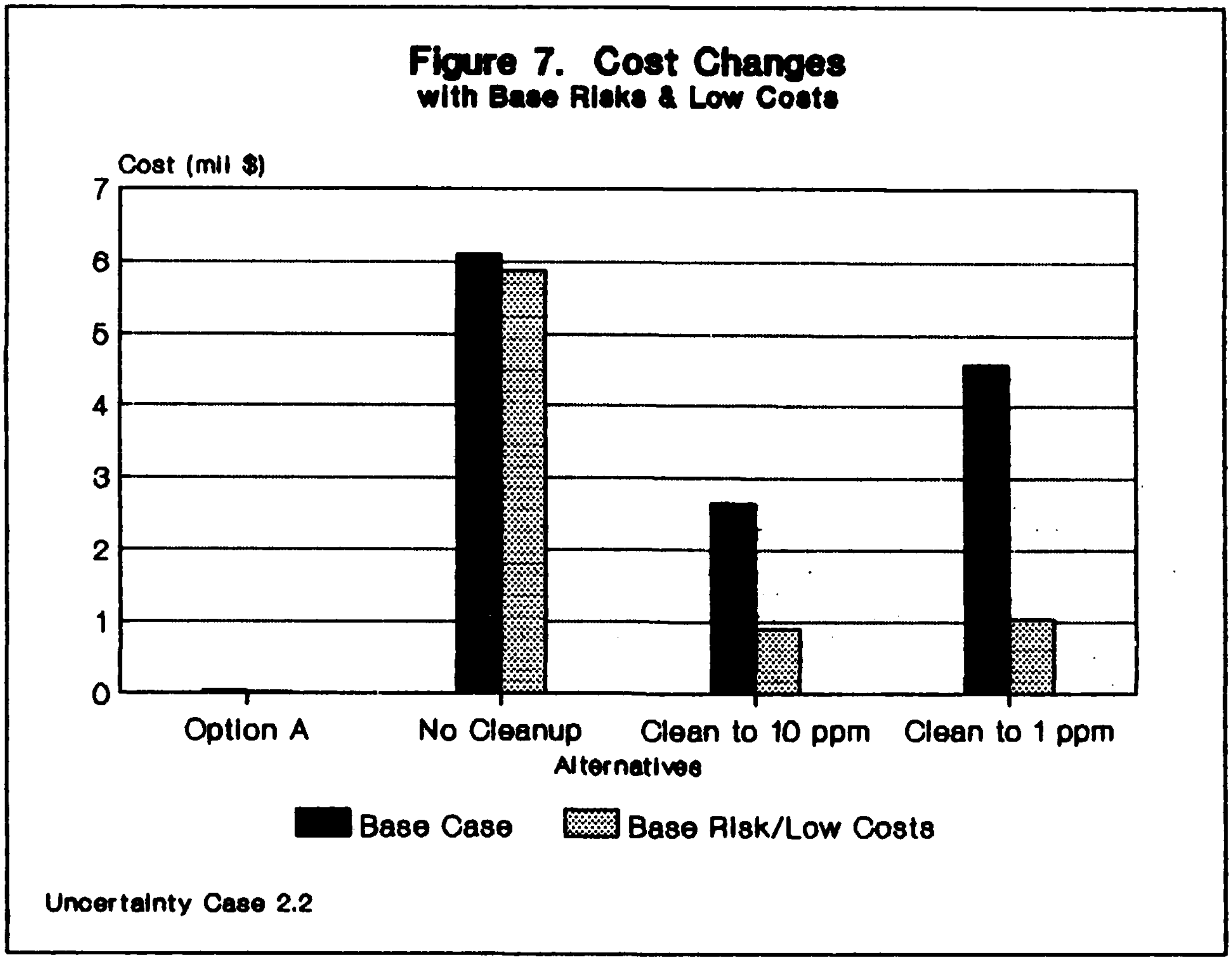


Figure 7. Cost Changes
with Base Risks & Low Costs
Cost (mil $)
7
6
5
4
3
2
1
0
Option A
No Cleanup
Clean to 10 ppm
Clean to 1 ppm
Alternatives
Base Case
Base Risk/Low Costs
Uncertainty Case 2.2

base case. Proper disposal is by far the lowest cost option, and a 10 ppm cleanup is the most cost effective alternative when only considering improper disposal (Also see Table B.12 in Appendix B.)

Uncertainty Case 3: Worst Case Human Risk Estimate

The opposite of uncertainty case 1, larger values of selected risk parameters were adjusted to yield a worst case human risk estimate.

Parameter	Base Case	Uncertainty Case 3
Air Inhalation		
Absorption rate	0.3	0.6
Soil - Dermal Absorption		
Absorption rate	0.03	0.5
Duration - Lifetime fraction	0.5	1.0
Soil Ingestion		
Absorption rates - all age groups	0.5	0.75
Exposure durations	0.5 x age group interval	1.0 x age group interval
Food Crop Ingestion		
Absorption rates (all age groups)	0.3	0.5
Exposure durations	same as for soil ingestion	
Fish Ingestion		
Background concentration (ppm)	0.1	0.3
Absorption rate	0.75	0.86
Duration (lifetime fraction)	0.3	1.0

Results - Case 3 Figure 8 depicts the worst case vs. base case human risk estimate, with the former about one order of magnitude greater than the latter. Figure 9 shows the total cost comparison. The costs for the No Cleanup alternative are five times greater whereas the costs of the remediation alternatives are about 1.5 to 2 times greater than those of the base case. (The dramatic increase in human health litigation under No Cleanup is most likely an unrealistic

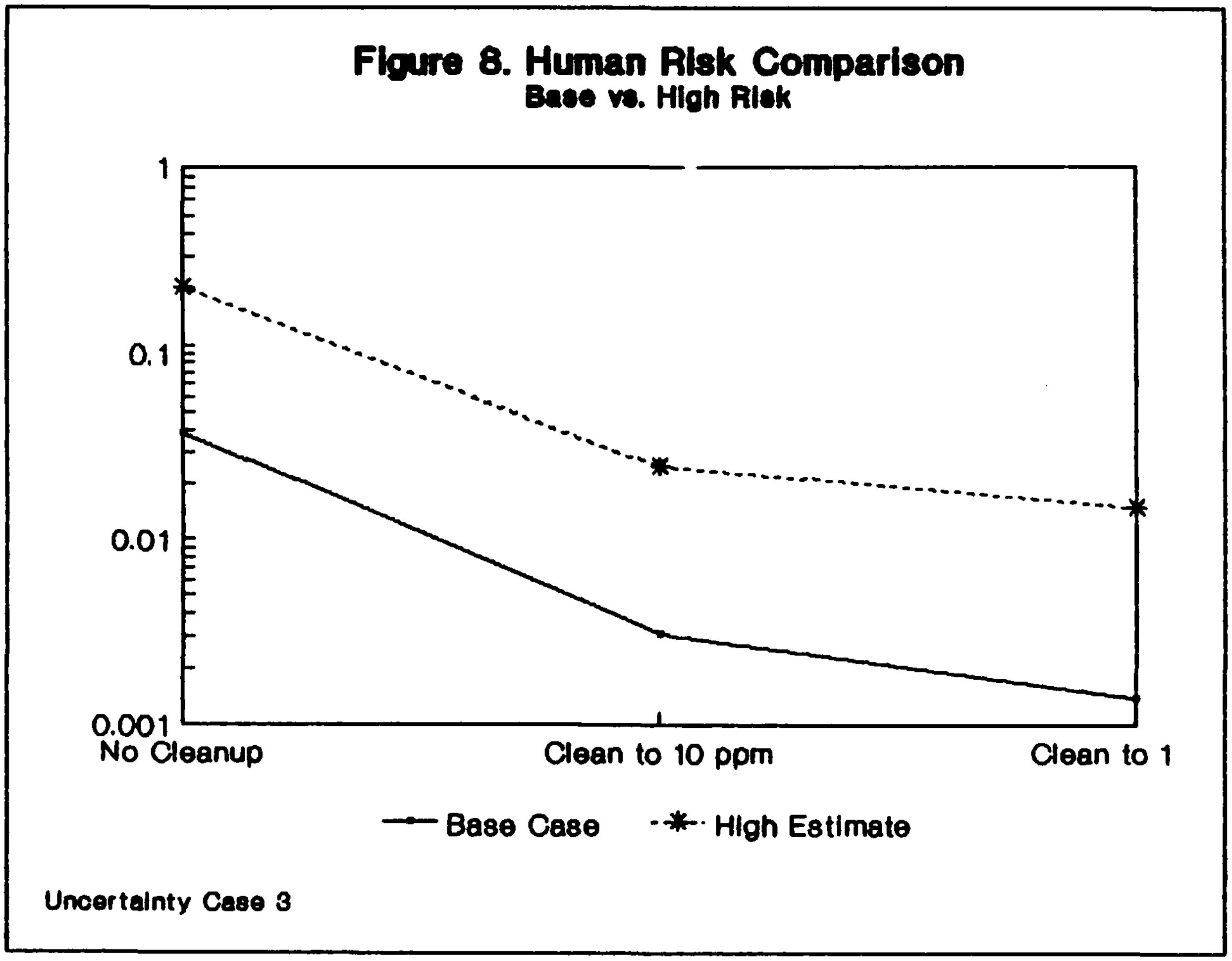


Figure 8. Human Risk Comparison
Base vs. High Risk
1
0.1
0.01
0.001
No Cleanup
Clean to 10 ppm
Clean to 1
Base Case
High Estimate
Uncertainty Case 3

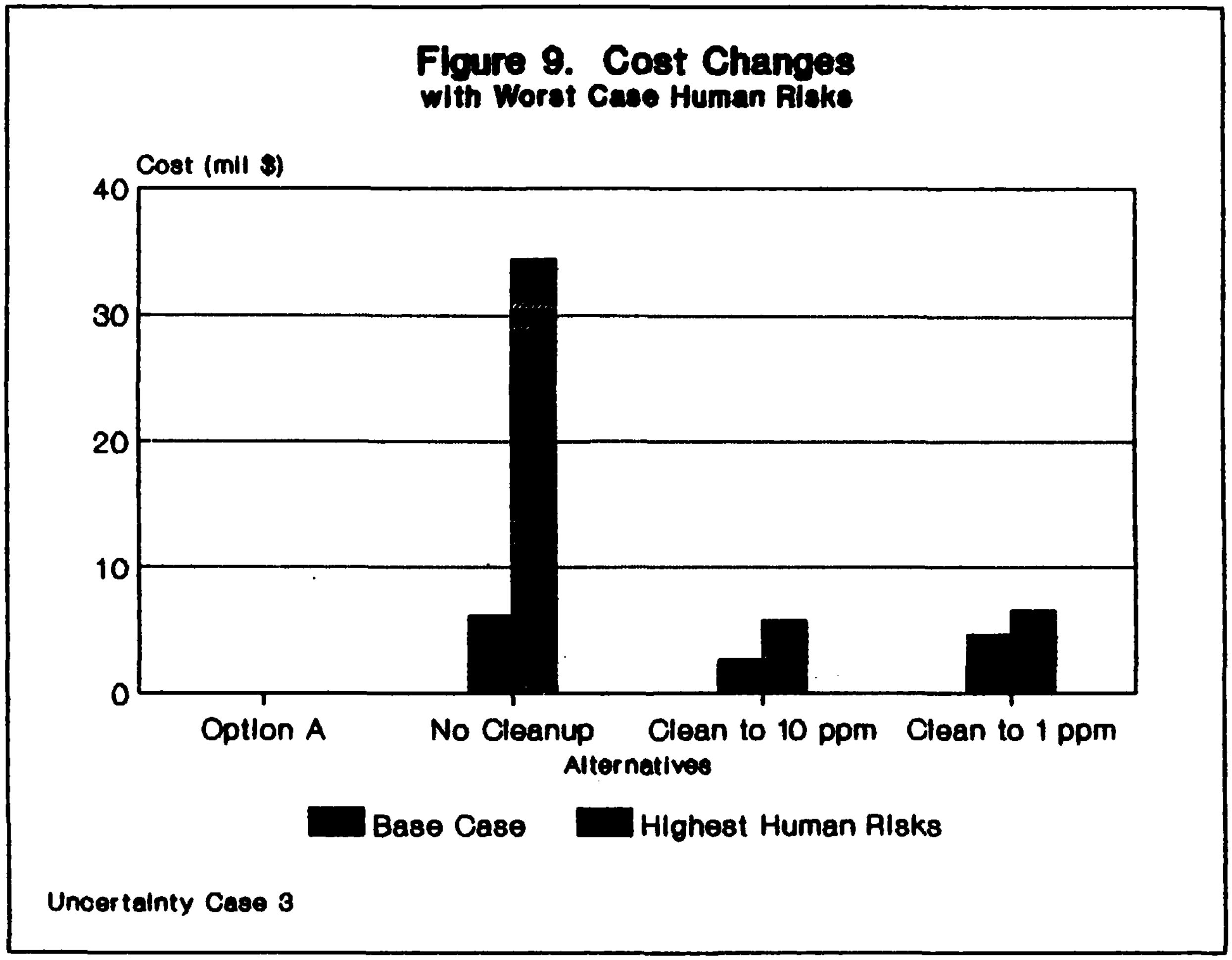


Figure 9. Cost Changes
with Worst Case Human Risks
Cost (mil $)
40
30
20
10
0
Option A
No Cleanup
Clean to 10 ppm
Clean to 1 ppm
Alternatives
Base Case
Highest Human Risks
Uncertainty Case 3

overestimate; as such, it shows to some degree the limited accuracy and validity of the computational methodology employed in this case study. Also see Tables B.13 through B.16 in Appendix B.)

Uncertainty Case 4: Increased Ecological Risks

In this case, the PCB concentrations in the media of interest are increased by a factor of ten.

Results - Case 4 The total percent reductions in biomass are correspondingly increased tenfold. With respect to the effect on total costs, since environmental litigation costs are relatively small under each alternative for improper disposal, the effect on total costs is virtually negligible. (See Tables B.17 through B.20 in Appendix B.)

Uncertainty Case 5: High Cost with Base Case Risk Estimate

Selected cost factors are increased to obtain a high estimate of total costs.

Parameter	Base Case	Uncertainty Case 5
Volume of Soil Excavated (cubic yards)		
Cleanup to 10 ppm	1666	2500
Cleanup to 1 ppm	3600	5000
Unit Costs		
Incineration - liquid ($/ton)	350	450
Incineration - solid ($/cu yd)	500	650
Transportation ($/cu yd-mile)	0.5	1.0
Excavation & Backfill ($/cu yd)	100	125
Interest rate (%)	8	6
Inflation rate (%)	2	3
Real interest rate	5.9	2.9
Human Health Litigation (mil $ per case)	1.0	2.0
Environmental Litigation (mil $)	2.0	3.0

Results - Case 5 See Figure 10 (and Table B.21, Appendix B). Total costs are virtually doubled for all alternatives.

Summary of Uncertainty Analysis

The uncertainty analysis provides a range of low and high human risks and total costs for the alternative methods of disposal/remediaton. Figure 11 combines the base case with the high and low human risk estimates. It illustrates the fact that the use of conservative assumptions and values for all inputs may greatly overestimate the actual risks of carcinogenicity. Figure 12 summarizes the ranges of total costs assuming base case human risk values.

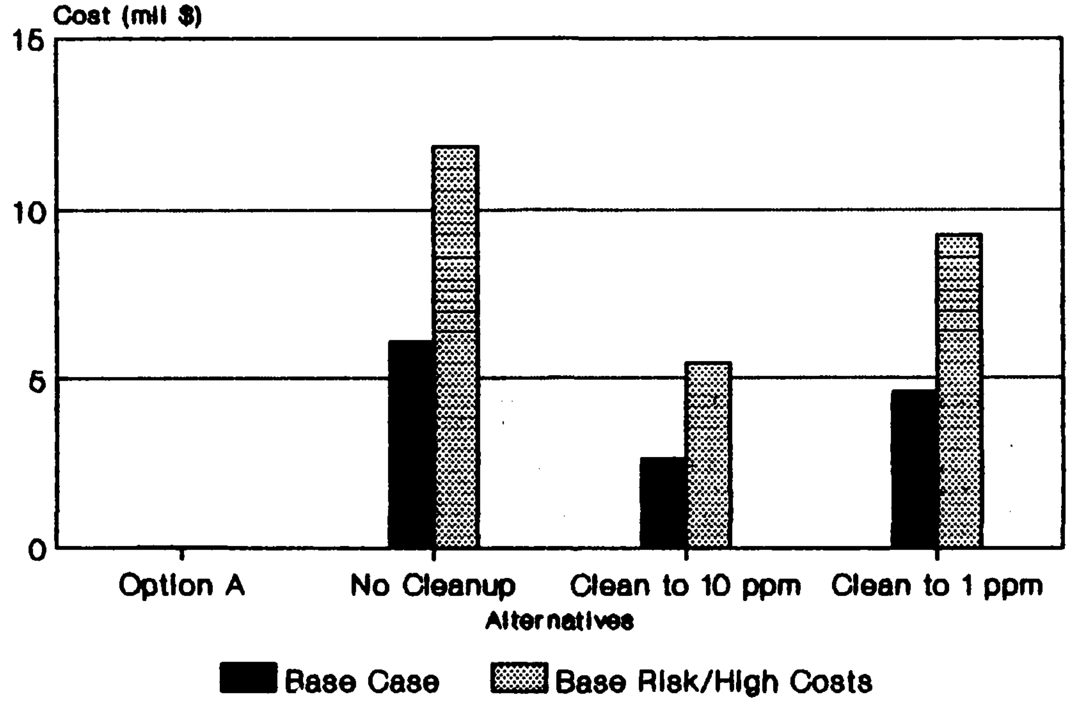
In no case was improper disposal more cost effective than proper disposal. This conclusion is primarily due to the fact that the cost elements under consideration take on greater significance when improper disposal occurs; in particular, the destruction costs are much greater for remediation of an improperly disposed waste stream, due to the greater quantity of waste material requiring treatment.

SUMMARY

Responsible parties face dire financial and other consequences if regulations for treatment and disposal of hazardous wastes are not followed properly. Although it was easier to "get away" with cutting corners in the past, present day focus on hazardous waste problems increases the chances of regrets for the generator.

PCBs are a class of chemicals whose use in many applications, coupled with liberal disposal practices, has led to widespread contamination of the environment. Because of their persistence and ability to bioaccumulate, PCBs will remain in the environment for the foreseeable future, even though their production ceased over ten years ago. Various studies indicate that PCBs may cause adverse health effects in humans and ecological endpoints, although the collective results of these studies are inconclusive. Regardless,

Figure 10. Cost Changes
with Base Risk/High Cost Factors



Uncertainty Case 5

Figure 11. Human Risk Comparison
Risk Range

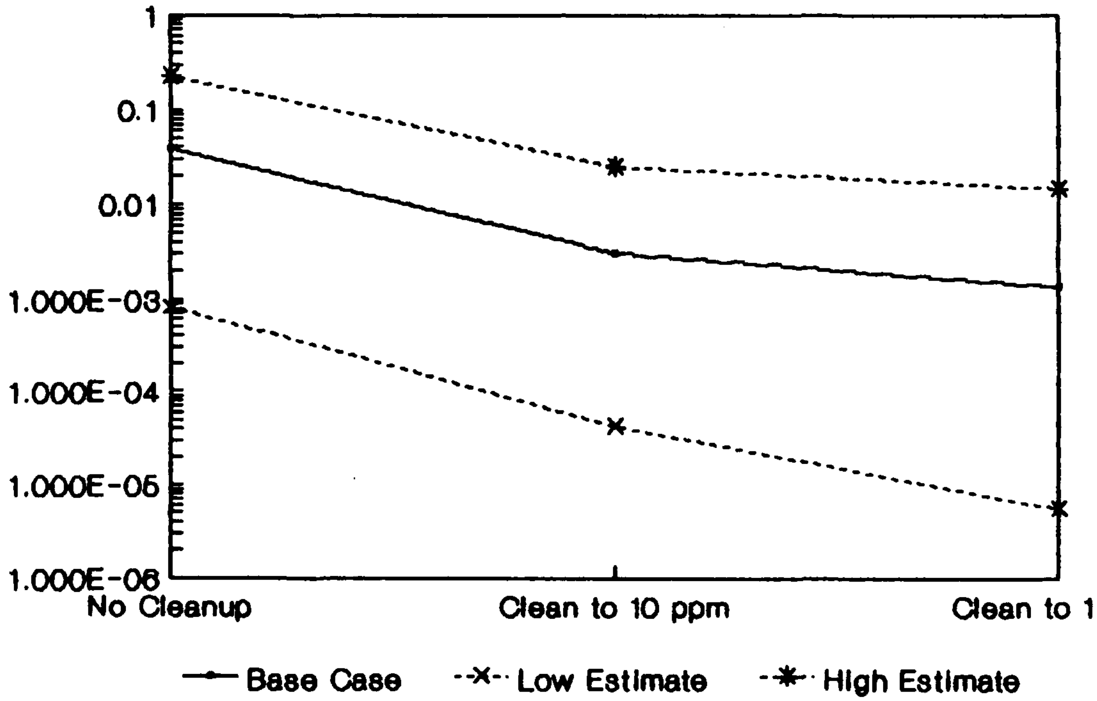
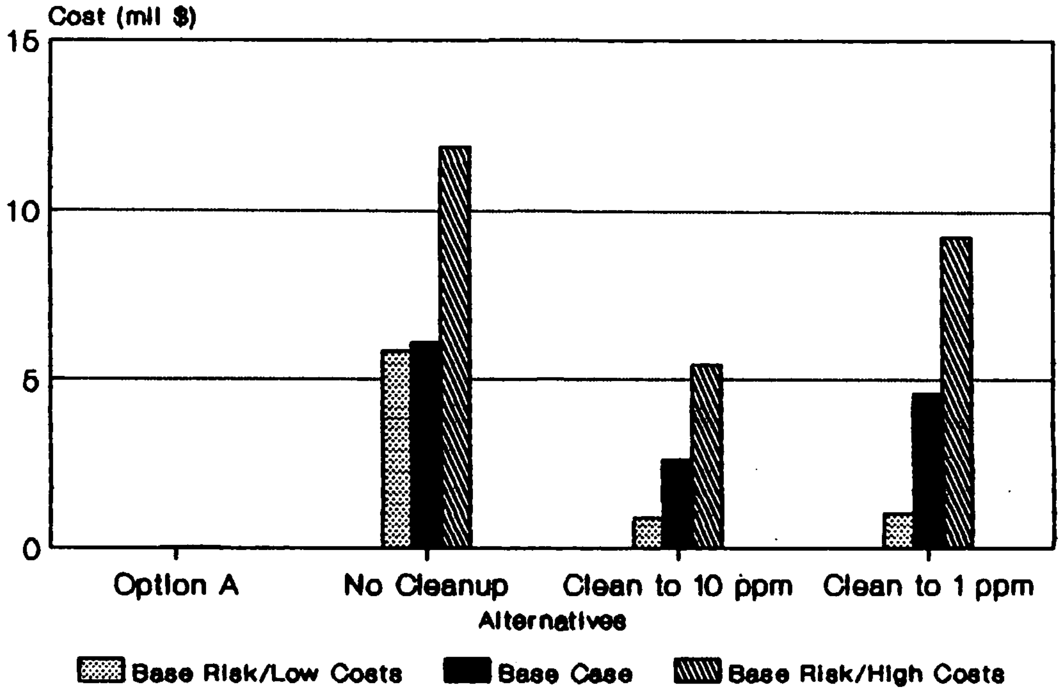


Figure 12. Cost Range
with Base Risk



regulations and criteria have been established to reduce exposures to PCBs.

Several bodies of legislation have been enacted to reduce contamination of the environment with hazardous wastes (including PCBs), as well as remediate contamination due to inadequate disposal practices. Fulfillment of the requirements called for in these laws can be very costly to the responsible parties and society as a whole. The establishment of cleanup levels for a given hazardous waste site can be a very complex task, and may lead to overly stringent requirements which could substantially increase the costs of remediation.

Risk assessments are an integral part of hazardous waste management; they factor into the prioritization of hazardous waste problems and the selection of remedial action alternatives. Unfortunately, present day methodologies for risk assessment are based on insufficient information; inherently conservative assumptions often lead to substantial overestimations of risk, a situation which may spawn excessive remedial efforts.

The results of this case study indicate that the total cost of improper disposal may be far greater than proper disposal. When considering only the former, three plausible alternative actions (in order of decreasing costs) are No Cleanup, Clean up to 1 ppm PCB soil, and cleanup to 10 ppm soil. For no cleanup, the driving factor is the cost of litigation which is based on a human health risk assessment that estimates the increased incidence of human cancers in the population exposed. For cleanup to 1 ppm, the human and ecological risks and ensuing litigation costs are reduced further, but the cost of remediation is substantially higher, making a 10 ppm cleanup the most cost effective alternative.

CONCLUSIONS/RECOMMENDATIONS

PCBs certainly deserve to be treated in a conservative manner, but their true threat to human health and ecosystems may be exag-

gerated. The uncertainties and public perception of the risks they pose may have led to overregulation and may force future cleanup actions to be more extensive and costly than is really necessary. Moreover, many of the environmental problems created by PCBs could have been avoided if waste generators had had some foresight and followed rather costly treatment and disposal procedures, anticipating that the true total costs would actually be higher if "simpler" disposal measures were taken.

With regard to risk assessments, complex, time-consuming approaches may be necessary (because they are required), but certain assumptions with inherent uncertainties may undermine the value of a complex approach. Unfortunately, many elements of uncertainty will probably always remain, especially data on effects, epidemiological studies, etc. Perhaps the most important modifications to present practices would be to increase the level of activity devoted to ecological risks. Certain elements of the environment are more sensitive to exposure to toxic chemicals than humans are, and those elements must be accounted for. People must recognize that while chemicals may pose a threat directly to them, this threat may be exaggerated. The public at large needs to also show greater concern for the rest of the ecosystem, as opposed to the direct risk to itself; for ultimately, the quality of human life depends on the quality of our natural surroundings.

As described in the case study, many other possible outcomes with associated probabilities of occurrence were ignored, due to insufficient data and the fact that the case study was designed to follow the methods used in related efforts. Even though such probabilities are difficult to determine with confidence, and the incorporation of other scenarios could greatly increase the complexity of the analysis, such efforts should be attempted when the analysis is conducted by and/or for a waste generator.

APPENDIX A. APPLICABLE EQUATIONS

APPENDIX A. RISK CALCULATIONS

Costs of Proper Disposal

Total Cost = Cost of Transportation + Cost of Incineration

Transportation Cost = volume of waste material x distance to incinerator x unit cost of transportation x conversion factor(s)

Example: 10,000 gal x 1/(55 gal/drum) x 550 lb/drum x

(1/2000 lb/ton)) x $0.5/ton-mile x 500 miles

= $12,500

Incineration Cost = volume of waste x unit cost of incinerator x conversion factors

Example: 10,000 gal x 1/(55 gal/drum) x 550 lb/drum x

1/(2000 lb/ton) x $350/ton

= $17,500

Total Cost of Disposal = $12,500 + $17,500 = $30,000

Reduction Factors Linking PCB Soil Concentrations to Environmental Media Concentrations

Medium	Soil Concentration (mg/kg)	Reduction Factor	Concentration in Medium
Air	200.0	6.3E-04	0.126 mg/m3
Groundwater	200.0	5.0E-05	10 mcgm/L
Water Column	200.0	1.0E-08	2 ng/L
Sediments	200.0	5.0E-04	0.1 mg/kg

Mean Weight for Ages Below 18 Years

Body Weight (kg) = 3.14 kg + (3.52 kg/yr x age)

(Source: *Schaum, 1984*)

Human carcinogenic risk

$$\text{Consummate Relative Risk} = \frac{\text{Total Absolute Risk}}{\text{Total Background Risk}}$$

$$\text{Total Absolute Risk} = \sum \text{Risk}_i \text{ from pathway } i$$

$$\text{Total Background Risk} = \sum \text{Background Risk}_i \text{ from pathway } i$$

Absolute Risk $_i$ = 1 - exp (average daily intake from pathway i x potency factor

average daily intake = (mg/kg/day)
potency factor = $(\text{mg/kg/day})^{-1}$

Average daily intake = concentration of PCB at contact point (mg/kg)
x contact rate (g/day)
x absorption rate (dimensionless)
x duration of exposure (days)
x 1/average lifetime (70 years x 365 days)
x 1/average body weight (kg)
x 1 kg / 1000 g

Background Risk$_i$ = Same method as absolute risk except background PCB concentrations are used

For food crop and soil ingestion pathways,

$$\text{Average daily intake} = \frac{\text{intake from age interval } j}{70 \text{ years} \times 365 \text{ days per year}}$$

where

Intake from age interval j = PCB conc. in food or soil (mg/kg)
x contact rate (g/day)
x absorption rate
x duration of exposure (days)
x 1 kg/1000 g
x 1/Mean body weight for age interval j (kg)

Ecological Risk Assessment Methodology

Total percent reduction in biomass = %Reduction via Chronic Toxicity
+ %Reduction via Acute Toxicity
+ %Reduction via Reduction in prey biomass (indirect)

Percent Chronic Reduction = Relative Chronic Risk (RCR) x 10

Relative Chronic Risk = PCB Concentration in Medium x Chronic Toxicity Concentration

Percent Acute Reduction = Relative Acute Risk x 0.5

Relative Acute Risk = PCB Concentration in Medium x Acute Toxicity Concentration

Net Present Cost

$$\text{Net Present Cost} = \sum_{i} \text{Cost}\,(1 + i_r)^{-n_i} - \sum_{j} \text{Benefit}\,(1 + j_r)^{-nj}$$

where

i = cost element
i_r = real interest rate
n_i = year in which cost element i is realized
j = benefit element j (principal + interest)
n_j = year in which benefit j is realized

APPENDIX B. DETAILED RISK AND COST ANALYSES

Table B.1

RISK ANAYLSES - HUMAN

Base Case Soil Conc 200.0 ppm

Species/ Route	Back-ground Conc. (mg/kg)	Cntmnant Conc at Site (mg/kg)	Degradn/Dilution Factor	Cntmnant Conc at Intake (mg/kg)	Contact Rate (g/day)	Adsorp-tion Rate (g/g)	Dura-tion (days) or Life-time Frac-tion (yr/yr)	Body Weight (kg)	Amount Ingstd (mg)	(Cum) Intake (Rate) (mg/kg/dy)	Absolute Risk	Back-ground Risk	Relative Risk
Air	8.E-07 n	0.126 *	0.9	0.113	20.0	0.3	1.000	70.0		9.72E-06	7.48E-05	5.28E-10	1.42E+05
Grndwtr	3.E-05	1.E-02	1.0	1.E-02	1500.0	1.0	1.000	70.0		2.14E-04	1.65E-03	4.95E-06	3.33E+02
Soil													
Dermal	0.5	200.0	1.0	200.5	4.3	0.03	0.5	70.0		1.85E-04	1.42E-03	3.55E-06	4.01E+02
Ingestn	0.5	200.0	1.0	200.5	0.3	0.5	1.000						
0-1 yr	0.5	200.0	1.0	200.5	5.0	0.5	182.5	4.9	9.15E+01	7.36E-04			
1-5 yr	0.5	200.0	1.0	200.5	10.0	0.5	730	13.7	7.32E+02	2.89E-03			
5-70 yr	0.5	200.0	1.0	200.5	0.3	0.5	11863	70.0	3.57E+02	3.26E-03	2.48E-02	8.25E-06	3.01E+03
Food Crop	0.1	200.0	0.2	40.1		0.3							
0-1 yr	0.1	200.0	0.2	40.1	0.8	0.3	183	4.9	1.76E+00	1.41E-05			
0-5 yr	0.1	200.0	0.2	40.1	0.7	0.3	730	13.7	6.15E+00	3.22E-05			
5-12 yr	0.1	200.0	0.2	40.1	0.3	0.3	11863	70.0	4.28E+01	7.69E-05	5.92E-04	9.90E-07	5.98E+02
Fish Ingestion	0.10	200.00	0.0039	0.88	454.0	0.75	0.3	70.0		1.28E-03	9.84E-03	1.12E-03	8.76E+00

Absolute	Backgrnd	Relative
3.84E-02	1.14E-03	33.635

* Air concentration in mg/m3

Table B.2

RISK ANAYLSES - HUMAN

Duration (days) or

Base Case Soil Conc 10.0 ppm

Species/ Route	Background Conc. (mg/kg)	Cntmnant Conc at Site (mg/kg)	Degradn/ Dilution Factor	Cntmnant Conc at Intake (mg/kg)	Contact Rate (g/day)	Adsorption Rate (g/g)	Lifetime Fraction (yr/yr)	Body Weight (kg)	Amount Ingstd (mg)	(Cum) Intake (Rate) (mg/kg/dy)	Absolute Risk	Background Risk	Relative Risk
Air	8.E-07 n	0.006 *	0.9	0.006	20.0	0.3	1.000	70.0		4.86E-07	3.74E-06	5.28E-10	7.09E+03
Gradwtr	3.E-05	5.E-04	1.0	5.E-04	1500.0	1.0	1.000	70.0		1.07E-05	8.25E-05	4.95E-06	1.67E+01
Soil													
Dermal	0.5	10.0	1.0	10.5	4.3	0.03	0.5	70.0		9.68E-06	7.45E-05	3.55E-06	2.10E+01
Ingestn	0.5	10.0	1.0	10.5	0.3	0.5	1.000						
0-1 yr	0.5	10.0	1.0	10.5	5.0	0.5	182.5	4.9	4.79E+00	3.85E-05			
1-5 yr	0.5	10.0	1.0	10.5	10.0	0.5	730	13.7	3.83E+01	1.51E-04			
5-70 yr	0.5	10.0	1.0	10.5	0.3	0.5	11863	70.0	1.87E+01	1.71E-04	1.31E-03	8.25E-06	1.59E+02
Food Crop	0.1	10.0	0.2	2.1		0.3							
0-1 yr	0.1	10.0	0.2	2.1	0.8	0.3	183	4.9	9.20E-02	7.40E-07			
0-5 yr	0.1	10.0	0.2	2.1	0.7	0.3	730	13.7	3.22E-01	1.69E-06			
5-12 yr	0.1	10.0	0.2	2.1	0.3	0.3	11863	70.0	2.24E+00	4.03E-06	3.10E-05	9.90E-07	3.13E+01
Fish Ingestion	0.10	10.00	0.0039	0.14	454.0	0.75	0.3	70.0		2.03E-04	1.56E-03	1.12E-03	1.39E+00

Absolute	Backgrnd	Relative
3.07E-03	1.14E-03	2.688

* Air concentration in mg/m3

Table B.3

RISK ANAYLSES - HUMAN

Base Case Soil Conc 1.0 ppm

Species/ Route	Back-ground Conc. (mg/kg)	Cntmnant Conc at Site (mg/kg)	Degradn/ Dilution Factor	Cntmnant Conc at Intake (mg/kg)	Contact Rate (g/day)	Adsorption Rate (g/g)	Duration (days) or Life-time Fraction (yr/yr)	Body Weight (kg)	Amount Ingstd (mg)	(Cum) Intake (Rate) (mg/kg/dy)	Absolute Risk	Back-ground Risk	Relative Risk
Air	8.E-07 n	0.001 *	0.9	0.001	20.0	0.3	1.000	70.0		4.86E-08	3.74E-07	5.28E-10	7.09E+02
Grndwtr	3.E-05	5.E-05	1.0	5.E-05	1500.0	1.0	1.000	70.0		1.07E-06	8.25E-06	4.95E-06	1.67E+00
Soil													
Dermal	0.5	1.0	1.0	1.5	4.3	0.03	0.5	70.0		1.38E-06	1.06E-05	3.55E-06	3.00E+00
Ingestn	0.5	1.0	1.0	1.5	0.3	0.5	1.000						
0-1 yr	0.5	1.0	1.0	1.5	5.0	0.5	182.5	4.9	6.84E-01	5.51E-06			
1-5 yr	0.5	1.0	1.0	1.5	10.0	0.5	730	13.7	5.48E+00	2.16E-05			
5-70 yr	0.5	1.0	1.0	1.5	0.3	0.5	11863	70.0	2.67E+00	2.44E-05	1.88E-04	8.25E-06	2.28E+01
Food Crop	0.1	1.0	0.2	0.3		0.3							
0-1 yr	0.1	1.0	0.2	0.3	0.8	0.3	183	4.9	1.31E-02	1.06E-07			
0-5 yr	0.1	1.0	0.2	0.3	0.7	0.3	730	13.7	4.60E-02	2.41E-07			
5-12 yr	0.1	1.0	0.2	0.3	0.3	0.3	11863	70.0	3.20E-01	5.75E-07	4.43E-06	9.90E-07	4.47E+00
Fish Ingestion	0.10	1.00	0.0039	0.10	454.0	0.75	0.3	70.0		1.52E-04	1.17E-03	1.12E-03	1.04E+00

Absolute	Backgrnd	Relative
1.38E-03	1.14E-03	1.208

* Air concentration in mg/m3

Table B.4

RISK ANALYSES - ECOLOGICAL

Base Case
Soil Conc 200.000 ppm

(Reference only)(mg/kg if terrestrial)

	Bioconc Factor	Acute Tox (LC50) (mg/l)	Chronic Tox (mg/l)	Conc in Media (mg/l)	Relative Acute Risk	Relative Chronic Risk	Percent Acute Reductn	Percent Chronic Reducn	Percent Direct Reduction in Popn Biomass	Percent Indirect Reduction in Popn Biomass	Percent Total Reductn in Popn Biomass
Mink	1.000	6000	0.640	0.200	3.3E-05	3.1E-01	1.7E-05	3.125	3.125	--	3.125
AQUATIC											
Phytplnktn	--	0.015	1.0E-04	2.0E-06	1.3E-04	2.0E-02	6.7E-05	0.200	0.200	--	0.200
Invrtebrte	20000	0.100	0.002	2.0E-06	2.0E-05	1.0E-03	1.0E-05	0.010	0.010	0.200	0.210
Small fish	--	0.033	0.006	2.0E-06	6.1E-05	3.1E-04	3.0E-05	0.003	0.003	0.210	0.213
Large fish	42000	0.1	0.0015	2.0E-06	2.0E-05	1.3E-03	1.0E-05	0.013	0.013	0.213	0.227
Avian		2000	50.000	1.5E+00	7.5E-04	3.0E-02	3.8E-04	0.300	0.300	0.227	0.527
Criteria-based		0.002	1.4E-05	2.0E-06	0.001	0.143	5.0E-04	1.432			1.433

Table B.5

RISK ANALYSES - ECOLOGICAL

Base Case
Soil Conc 10.000 ppm

(Reference only)(mg/kg if terrestrial)

	Bioconc Factor	Acute Tox (LC50) (mg/l)	Chronic Tox (mg/l)	Conc in Media (mg/l)	Relative Acute Risk	Relative Chronic Risk	Percent Acute Reductn	Percent Chronic Reducn	Percent Direct Reduction in Popn Biomass	Percent Indirect Reductio in Popn Biomass	Percent Total Reducti in Popn Biomass
Mink	1.000	6000	0.640	0.010	1.7E-06	1.6E-02	8.3E-07	0.156	0.156	--	0.156
AQUATIC											
Phytplnktn	--	0.015	1.0E-04	1.0E-07	6.7E-06	1.0E-03	3.3E-06	0.010	0.010	--	0.010
Invrtebrte	20000	0.100	0.002	1.0E-07	1.0E-06	5.0E-05	5.0E-07	0.001	0.001	0.010	0.011
Small fish	--	0.033	0.006	1.0E-07	3.0E-06	1.6E-05	1.5E-06	0.000	0.000	0.011	0.011
Large fish	42000	0.1	0.0015	1.0E-07	1.0E-06	6.7E-05	5.0E-07	0.001	0.001	0.011	0.011
Avian		2000	50.000	1.5E+00	7.5E-04	3.0E-02	3.0E-04	0.300	0.300	0.011	0.312
Criteria-based		0.002	1.4E-05	1.1E-07	0.000	0.007	2.6E-05	0.075			0.075

Table B.6

RISK ANALYSES - ECOLOGICAL

Base Case
Soil Conc 1.000 ppm

	Biocone Factor (reference only)	Acute Tox (LC50) (mg/l) (mg/kg if terrestrial)	Chronic Tox (mg/l)	Conc in Media (mg/l)	Relative Acute Risk	Relative Chronic Risk	Percent Acute Reductn	Percent Chronic Reducn	Percent Direct Reduction in Popn Biomass	Percent Indirect Reduction in Popn Biomass	Percent Total Reductn in Popn Biomass
Mink	1.000	6000	0.640	0.001	1.7E-07	1.6E-03	8.3E-08	0.016	0.016	--	0.016
AQUATIC											
Phytplaktn	--	0.015	1.0E-04	1.0E-08	6.7E-07	1.0E-04	3.3E-07	0.001	0.001	--	0.001
Invrtebrte	20000	0.100	0.002	1.0E-08	1.0E-07	5.0E-06	5.0E-08	0.000	0.000	0.001	0.001
Small fish	--	0.033	0.006	1.0E-08	3.0E-07	1.6E-06	1.5E-07	0.000	0.000	0.001	0.001
Large fish	42000	0.1	0.0015	1.0E-08	1.0E-07	6.7E-06	5.0E-08	0.000	0.000	0.001	0.001
Avian		2000	50.000	1.5E+00	7.5E-04	3.0E-02	3.8E-04	0.300	0.300	0.001	0.302
Criteria-based		0.002	1.4E-05	1.5E-08	0.000	0.001	3.8E-06	0.011			0.011

Table B.7

RISK ANAYLSES - HUMAN

Duration (days) or Lifetime Fraction

Uncertainty Case 1.0
Soil Conc 200.0 ppm

Species/ Route	Background Conc. (mg/kg)	Catmnant Conc at Site (mg/kg)	Degradn/ Dilution Factor	Catmnant Conc at Intake (mg/kg)	Contact Rate (g/day)	Adsorption Rate (g/g)	Duration (days) or Lifetime Fraction (yr/yr)	Body Weight (kg)	Amount Ingstd (mg)	(Cum) Intake (Rate) (mg/kg/dy)	Absolute Risk	Background Risk	Relative Risk
Air	8.E-07 m	0.126 *	0.9	0.113	20.0	0.25	0.50	70.0		8.10E-06	3.52E-05	2.48E-10	1.42E+05
Grndwtr	3.E-05	1.E-02	1.0	1.E-02	1500.0	0.5	0.50	70.0		1.07E-04	4.65E-04	1.39E-06	3.33E+02
Soil													
Dermal	0.5	200.0	1.0	200.5	4.3	0.01	0.3	70.0		3.69E-05	1.60E-04	4.00E-07	4.01E+02
Ingestn	0.5	200.0	1.0	200.5	0.3	0.20	1.000						
0-1 yr	0.5	200.0	1.0	200.5	0.05	0.20	91	4.9	1.83E-01	1.47E-06			
1-5 yr	0.5	200.0	1.0	200.5	0.10	0.20	365	13.7	1.46E+00	5.71E-06			
5-70 yr	0.5	200.0	1.0	200.5	0.03	0.20	5931	70.0	7.14E+00	1.09E-05	4.73E-05	1.86E-07	2.54E+02
Food Crop	0.1	200.0	0.2	40.1		0.2							
0-1 yr	0.1	200.0	0.2	40.1	0.8	0.2	91	4.9	5.05E-01	4.69E-06			
0-5 yr	0.1	200.0	0.2	40.1	0.7	0.2	365	13.7	2.05E+00	1.06E-05			
5-70 yr	0.1	200.0	0.2	40.1	0.3	0.2	5931	70.0	1.43E+01	2.10E-05	9.12E-05	3.72E-07	2.45E+02
Fish Ingestion	0.10	200.00	0.0039	0.88	6.5	0.50	0.04	70.0		1.63E-06	7.09E-06	8.06E-07	8.80E+00

* Air concentration in mg/m3

Absolute	Backgrnd	Relative
8.06E-04	3.16E-06	255.147

Table B.8

RISK ANAYLSES - HUMAN

Uncertainty Case 1.0
Soil Conc 10.0 ppm

Species/ Route	Back-ground Conc. (mg/kg)	Cntmnant Conc at Site (mg/kg)	Degradn/ Dilution Factor	Cntmnant Conc at Intake (mg/kg)	Contact Rate (g/day)	Adsorp-tion Rate (g/g)	Dura-tion (days) or Life-time Frac-tion (yr/yr	Body Weight (kg)	Amount Ingstd (mg)	(Cum) Intake (Rate) (mg/kg/dy)	Absolute Risk	Back-ground Risk	Relative Risk
Air	8.E-07 n	0.006 *	0.9	0.006	20.0	0.25	0.50	70.0		4.05E-07	1.76E-06	2.48E-10	7.09E+03
Grndwtr	3.E-05	5.E-04	1.0	5.E-04	1500.0	0.5	0.50	70.0		5.36E-06	2.32E-05	1.39E-06	1.67E+01
Soil													
Dermal	0.5	10.0	1.0	10.5	4.3	0.01	0.3	70.0		[illegible]E-06	8.40E-06	4.00E-07	2.10E+01
Ingestn	0.5	10.0	1.0	10.5	0.3	0.20	1.000						
0-1 yr	0.5	10.0	1.0	10.5	0.05	0.20	91	4.9	9.58E-03	7.68E-08			
1-5 yr	0.5	10.0	1.0	10.5	0.10	0.20	365	13.7	7.67E-02	2.99E-07			
5-70 yr	0.5	10.0	1.0	10.5	0.03	0.20	5931	70.0	3.74E-01	5.71E-07	2.48E-06	1.86E-07	1.33E+01
Food Crop	0.1	10.0	0.2	2.1		0.2							
0-1 yr	0.1	10.0	0.2	2.1	0.0	0.2	91	4.9	3.07E-02	2.46E-07			
0-5 yr	0.1	10.0	0.2	2.1	0.7	0.2	365	13.7	1.07E-01	5.57E-07			
5-70 yr	0.1	10.0	0.2	2.1	0.3	0.2	5931	70.0	7.47E-01	1.10E-06	4.70E-06	3.72E-07	1.28E+01
Fish Ingestion	0.10	10.00	0.0039	0.14	6.5	0.50	0.04	70.0		2.50E-07	1.12E-06	8.06E-07	1.39E+00

Absolute	Backgrnd	Relative
4.18E-05	3.16E-06	13.226

* Air concentration in mg/m3

Table B.9

RISK ANAYLSES - HUMAN

Uncertainty Case 1.0
Soil Conc 1.0 ppm

Species/ Route	Back-ground Conc. (mg/kg)	Cntmnant Conc at Site (mg/kg)	Degradn/ Dilution Factor	Cntmnant Conc at Intake (mg/kg)	Contact Rate (g/day)	Adsorp-tion Rate (g/g)	Dura-tion (days) or Life-time Frac-tion (yr/yr)	Body Weight (kg)	Amount Ingstd (mg)	(Cum) Intake (Rate) (mg/kg/dy)	Absolute Risk	Back-ground Risk	Relative Risk
Air	8.E-07 n	0.001 *	0.9	0.001	20.0	0.25	0.50	70.0		4.05E-08	1.76E-07	2.48E-10	7.09E+02
Grndwtr	3.E-05	5.E-05	1.0	5.E-05	1500.0	0.5	0.50	70.0		5.36E-07	2.32E-06	1.39E-06	1.67E+00
Soil													
Dermal	0.5	1.0	1.0	1.5	4.3	0.01	0.3	70.0		2.76E-07	1.20E-06	4.00E-07	3.00E+00
Ingestn	0.5	1.0	1.0	1.5	0.3	0.20	1.000						
0-1 yr	0.5	1.0	1.0	1.5	0.05	0.20	91	4.9	1.37E-03	1.10E-08			
1-5 yr	0.5	1.0	1.0	1.5	0.10	0.20	365	13.7	1.10E-02	4.27E-08			
5-70 yr	0.5	1.0	1.0	1.5	0.03	0.20	5931	70.0	5.34E-02	8.16E-08	3.54E-07	1.06E-07	1.90E+00
Food Crop	0.1	1.0	0.2	0.3		0.2							
0-1 yr	0.1	1.0	0.2	0.3	0.8	0.2	91	4.9	4.38E-03	3.51E-08			
0-5 yr	0.1	1.0	0.2	0.3	0.7	0.2	365	13.7	1.53E-02	7.95E-08			
5-70 yr	0.1	1.0	0.2	0.3	0.3	0.2	5931	70.0	1.07E-01	1.57E-07	6.83E-07	3.72E-07	1.83E+00
Fish Ingestion	0.10	1.00	0.0039	0.10	6.5	0.50	0.04	70.0		1.93E-07	8.37E-07	8.06E-07	1.04E+00

Absolute	Backgrnd	Relative
5.57E-06	3.16E-06	1.765

* Air concentration in mg/m3

Table B.10. COST ANALYSES Uncertainty Case 1

Distance to burn facility 500 miles

Unit Costs

Incineration (liquid)	350.0 $/ton
Incineration (solid)	500.0 $/cu yd
Transportation	0.50 $/cu yd-mile
Excavate & Backfill	100.0 $/cu yd

Interest rate 0.080

Discount Factor 1.059

ALTERNATIVES
(cost values are in million dollars)

Item	Year Cost Realized	OPTION A Incinerate	OPTION B No Cleanup	OPTION B Cleanup to 10 ppm	OPTION B Cleanup to 1 ppm
Quantity of Waste Material		10,000 gal		1666.000 cu yd	3600.000 cu yd
Immediate Destruction		0.030	N/A	N/A	N/A
RI/FS	6		0.423	0.423	0.423
Remediation	8	N/A	N/A		
Excavate & Backfill				0.263	0.569
Transportation				0.658	1.422
Incineration				1.316	2.844
Overhead				0.559	1.209
Contingency				0.224	0.483
Total Remdiatn	8	0.000	0.000	3.020	6.526
Fines	7	0.000	0.100	0.000	0.000
Human Health Litigation	7	0.000	0.180	0.009	0.001
Environmental Litigation	8	0.000	0.007	3.58E-04	3.58E-05
"Benefits" of Invested Capital	5	0.000	0.044	0.044	0.044
Net Present Cost		0.030	0.459	2.185	4.399

Table B.11. COST ANALYSES Uncertainty Case 2.1

Distance to burn facility 500 miles

Unit Costs

Incineration (liquid)	250.0 $/ton
Incineration (solid)	375.0 $/cu yd
Transportation	0.25 $/cu yd-mile
Excavate & Backfill	80.0 $/cu yd

Interest rate 0.100

Discount Factor 1.100

ALTERNATIVES
(cost values are in million dollars)

Item	Year Cost Realized	OPTION A Incinerate	OPTION B No Cleanup	OPTION B Cleanup to 10 ppm	OPTION B Cleanup to 1 ppm
Quantity of Waste Material		10,000 gal		500.000 cu yd	1000.000 cu yd
Immediate Destruction		0.019	N/A	N/A	N/A
RI/FS	9	·	0.177	0.177	0.177
Remediation	11	N/A	N/A		
Excavate & Backfill				0.094	0.189
Transportation				0.147	0.295
Incineration				0.442	0.884
Overhead				0.171	0.342
Contingency				0.068	0.137
Total Remdiatn	9	0.000	0.000	0.923	1.846
Fines	9	0.000	0.100	0.000	0.000
Human Health Litigation	15	0.000	0.505	0.026	0.003
Environmental Litigation	12	0.000	0.014	7.11E-04	7.11E-05
"Benefits" of Invested Capital	5	0.000	0.030	0.030	0.030
Net Present Cost		0.019	0.224	0.454	0.840

Table B.12. COST ANALYSES — Uncertainty Case 2.2

Distance to burn facility — 500 miles

Unit Costs

Incineration (liquid)	250.0 $/ton
Incineration (solid)	375.0 $/cu yd
Transportation	0.25 $/cu yd-mile
Excavate & Backfill	80.0 $/cu yd

Interest rate 0.100

Discount Factor 1.100

ALTERNATIVES
(cost values are in million dollars)

Item	Year Cost Realized	OPTION A: Incinerate	OPTION B: No Cleanup	OPTION B: Cleanup to 10 ppm	OPTION B: Cleanup to 1 ppm
Quantity of Waste Material		10,000 gal		500.000 cu yd	1000.000 cu yd
Immediate Destruction		0.019	N/A	N/A	N/A
RI/FS	9		0.177	0.177	0.177
Remediation	11	N/A	N/A		
Excavate & Backfill				0.094	0.189
Transportation				0.147	0.295
Incineration				0.442	0.884
Overhead				0.171	0.342
Contingency				0.068	0.137
Total Remdiatn	9	0.000	0.000	0.923	1.846
Fines	9	0.000	0.100	0.000	0.000
Human Health Litigation	15	0.000	24.042	1.921	0.864
Environmental Litigation	12	0.000	0.014	7.11E-04	7.11E-05
"Benefits" of Invested Capital	5	0.000	0.030	0.030	0.030
Net Present Cost		0.019	5.859	0.908	1.046

Table B.13

RISK ANAYLSES - HUMAN

Uncertainty Case 3.0
Soil Conc 200.0 ppm

Species/ Route	Back-ground Conc. (mg/kg)	Cntmnant Conc at Site (mg/kg)	Degradn/Dilution Factor	Cntmnant Conc at Intake (mg/kg)	Contact Rate (g/day)	Adsorption Rate (g/g)	Duration (days) or Life-time Frac-tion (yr/yr)	Body Weight (kg)	Amount Ingstd (mg)	(Cum) Intake (Rate) (mg/kg/dy)	Absolute Risk	Back-ground Risk	Relative Risk
Air	8.E-07 n	0.126 *	0.9	0.113	20.0	0.60	1.00	70.0		1.94E-05	1.50E-04	1.06E-09	1.42E+05
Grndwtr	3.E-05	1.E-02	1.0	1.E-02	1500.0	1.0	1.00	70.0		2.14E-04	1.65E-03	4.95E-06	3.33E+02
Soil													
Dermal	0.5	200.0	1.0	200.5	4.3	0.50	1.0	70.0		6.16E-03	4.63E-02	1.10E-04	3.92E+02
Ingestn	0.5	200.0	1.0	200.5	0.3	0.75	1.000						
0-1 yr	0.5	200.0	1.0	200.5	5.00	0.75	365	4.9	2.74E+02	2.22E-03			
1-5 yr	0.5	200.0	1.0	200.5	10.00	0.75	1460	13.7	2.20E+03	8.08E-03			
5-70 yr	0.5	200.0	1.0	200.5	0.30	0.75	23725	70.0	1.07E+03	1.73E-02	1.24E-01	1.24E-05	1.01E+04
Food Crop	0.1	200.0	0.2	40.1		0.5							
0-1 yr	0.1	200.0	0.2	40.1	0.8	0.5	365	4.9	5.05E+00	4.74E-05			
0-5 yr	0.1	200.0	0.2	40.1	0.7	0.5	1460	13.7	2.05E+01	1.10E-04			
5-70 yr	0.1	200.0	0.2	40.1	0.3	0.5	23725	70.0	1.43E+02	1.23E-03	9.40E-03	1.65E-06	5.70E+03
Fish Ingestion	0.30	200.00	0.0039	1.08	454.0	0.86	1.00	70.0		6.02E-03	4.53E-02	1.28E-02	3.54E+00

* Air concentration in mg/m3

Absolute	Backgrnd	Relative
2.27E-01	1.29E-02	17.563

Table B.14

RISK ANAYLSES - HUMAN

Uncertainty Case 3.0
Soil Conc 10.0 ppm

Species/ Route	Back-ground Conc. (mg/kg)	Catmnant Conc at Site (mg/kg)	Degrada/ Dilution Factor	Catmnant Conc at Intake (mg/kg)	Contact Rate (g/day)	Adsorp-tion Rate (g/g)	Dura-tion (days) or Life-time Frac-tion (yr/yr)	Body Weight (kg)	Amount Ingstd (mg)	(Cum) Intake (Rate) (mg/kg/dy)	Absolute Risk	Back-ground Risk	Relative Risk
Air	8.E-07 m	0.006 *	0.9	0.006	20.0	0.60	1.00	70.0		9.72E-07	7.40E-06	1.06E-09	7.09E+03
Grndwtr	3.E-05	5.E-04	1.0	5.E-04	1500.0	1.0	1.00	70.0		1.07E-05	8.25E-05	4.95E-06	1.67E+01
Soil													
Dermal	0.5	10.0	1.0	10.5	4.3	0.50	1.0	70.0		3.23E-04	2.40E-03	1.10E-04	2.10E+01
Ingestn	0.5	10.0	1.0	10.5	0.3	0.75	1.000						
0-1 yr	0.5	10.0	1.0	10.5	5.00	0.75	365	4.9	1.44E+01	1.16E-04			
1-5 yr	0.5	10.0	1.0	10.5	10.00	0.75	1460	13.7	1.15E+02	4.65E-04			
5-70 yr	0.5	10.0	1.0	10.5	0.30	0.75	23725	70.0	5.61E+01	9.04E-04	6.93E-03	1.24E-05	5.60E+02
Food Crop	0.1	10.0	0.2	2.1		0.5							
0-1 yr	0.1	10.0	0.2	2.1	0.0	0.5	365	4.9	3.07E-01	2.48E-06			
0-5 yr	0.1	10.0	0.2	2.1	0.7	0.5	1460	13.7	1.07E+00	5.74E-06			
5-70 yr	0.1	10.0	0.2	2.1	0.3	0.5	23725	70.0	7.47E+00	6.42E-05	4.94E-04	1.65E-06	3.00E+02
Fish Ingestion	0.30	10.00	0.0039	0.34	454.0	0.86	1.00	70.0		1.09E-03	1.45E-02	1.20E-02	1.13E+00

* Air concentration in mg/m3

Absolute	Backgrnd	Relative
2.45E-02	1.29E-02	1.090

Table B.15

RISK ANAYLSES - HUMAN

Uncertainty Case 3.0
Soil Conc 1.0 ppm

Species/ Route	Back- ground Conc. (mg/kg)	Cntmnant Conc at Site (mg/kg)	Degradn/ Dilution Factor	Cntmnant Conc at Intake (mg/kg)	Contact Rate (g/day)	Adsorp- tion Rate (g/g)	Dura- tion (days) or Life- time Frac- tion (yr/yr)	Body Weight (kg)	Amount Ingstd (mg)	(Cum) Intake (Rate) (mg/kg/dy)	Absolute Risk	Back- ground Risk	Relative Risk
Air	8.E-07 n	0.001 *	0.9	0.001	20.0	0.60	1.00	70.0		9.72E-08	7.48E-07	1.06E-09	7.09E+02
Grndwtr	3.E-05	5.E-05	1.0	5.E-05	1500.0	1.0	1.00	70.0		1.07E-06	8.25E-06	4.95E-06	1.67E+00
Soil													
Dermal	0.5	1.0	1.0	1.5	4.3	0.50	1.0	70.0		4.61E-05	3.55E-04	1.18E-04	3.00E+00
Ingestn	0.5	1.0	1.0	1.5	0.3	0.75	1.000						
0-1 yr	0.5	1.0	1.0	1.5	5.00	0.75	365	4.9	2.05E+00	1.66E-05			
1-5 yr	0.5	1.0	1.0	1.5	10.00	0.75	1460	13.7	1.64E+01	6.64E-05			
5-70 yr	0.5	1.0	1.0	1.5	0.30	0.75	23725	70.0	8.01E+00	1.29E-04	9.93E-04	1.24E-05	8.03E+01
Food Crop	0.1	1.0	0.2	0.3		0.5							
0-1 yr	0.1	1.0	0.2	0.3	0.8	0.5	365	4.9	4.30E-02	3.55E-07			
0-5 yr	0.1	1.0	0.2	0.3	0.7	0.5	1460	13.7	1.53E-01	8.19E-07			
5-70 yr	0.1	1.0	0.2	0.3	0.3	0.5	23725	70.0	1.07E+00	9.18E-06	7.07E-05	1.65E-06	4.28E+01
Fish Ingestion	0.30	1.00	0.0039	0.30	454.0	0.06	1.00	70.0		1.70E-03	1.30E-02	1.28E-02	1.01E+00

Absolute	Backgrnd	Relative
1.44E-02	1.29E-02	1.113

* Air concentration in mg/m3

Table B.16. COST ANALYSES — Uncertainty Case 3

Distance to burn facility: 500 miles

Unit Costs

Incineration (liquid)	350.0 $/ton
Incineration (solid)	500.0 $/cu yd
Transportation	0.50 $/cu yd-mile
Excavate & Backfill	100.0 $/cu yd

Interest rate 0.080

Discount Factor 1.059

ALTERNATIVES
(cost values are in million dollars)

Item	Year Cost Realized	OPTION A Incinerate	OPTION B No Cleanup	OPTION B Cleanup to 10 ppm	OPTION B Cleanup to 1 ppm
Quantity of Waste Material		10,000 gal		1666.000 cu yd	3600.000 cu yd
Immediate Destruction		0.030	N/A	N/A	N/A
RI/FS	6		0.423	0.423	0.423
Remediation	8	N/A	N/A		
Excavate & Backfill				0.263	0.569
Transportation				0.658	1.422
Incineration				1.316	2.844
Overhead				0.559	1.209
Contingency				0.224	0.483
Total Remdiatn	8	0.000	0.000	3.020	6.526
Fines	7	0.000	0.100	0.000	0.000
Human Health Litigation	7	0.000	50.857	5.472	3.222
Environmental Litigation	8	0.000	0.007	3.58E-04	3.58E-05
"Benefits" of Invested Capital	5	0.000	0.044	0.044	0.044
Net Present Cost		0.030	34.425	5.846	6.557

Table B.17

RISK ANALYSES - ECOLOGICAL

Uncertainty Case 4
Soil Conc 200.000 ppm

(Reference only)(mg/kg if terrestrial)

	Bioconc Factor	Acute Tox (LC50) (mg/l)	Chronic Tox (mg/l)	Conc in Media (mg/l)	Relative Acute Risk	Relative Chronic Risk	Percent Acute Reductn	Percent Chronic Reducn	Percent Direct Reduction in Popn Biomass	Percent Indirect Reduction in Popn Biomass	Percent Total Reductn in Popn Biomass
Mink	1.000	6000	0.640	2.000	3.3E-04	3.1E+00	1.7E-04	31.250	31.250	--	31.250
AQUATIC											
Phytplnktn	--	0.015	1.0E-04	2.0E-05	1.3E-03	2.0E-01	6.7E-04	2.000	2.001	--	2.001
Invrtebrte	20000	0.100	0.002	2.0E-05	2.0E-04	1.0E-02	1.0E-04	0.100	0.100	2.001	2.101
Small fish	--	0.033	0.006	2.0E-05	6.1E-04	3.1E-03	3.0E-04	0.031	0.032	2.101	2.132
Large fish	42000	0.1	0.0015	2.0E-05	2.0E-04	1.3E-02	1.0E-04	0.133	0.133	2.132	2.266
Avian		2000	50.000	1.5E+00	7.5E-04	3.0E-02	3.0E-04	0.300	0.300	2.266	2.566
Criteria-based		0.002	1.4E-05	2.0E-05	0.010	1.429	5.0E-03	14.286			14.291

Table B.18

RISK ANALYSES - ECOLOGICAL

Uncertainty Case 4
Soil Conc 10.000 ppm

(Reference only)(mg/kg if terrestrial)

	Bioconc Factor	Acute Tox (LC50) (mg/l)	Chronic Tox (mg/l)	Conc in Media (mg/l)	Relative Acute Risk	Relative Chronic Risk	Percent Acute Reductn	Percent Chronic Reducn	Percent Direct Reduction in Popn Biomass	Percent Indirect Reduction in Popn Biomass	Percent Total Reductn in Popn Biomass
Mink	1.000	6000	0.640	0.100	1.7E-05	1.6E-01	8.3E-06	1.563	1.563	--	1.563
AQUATIC											
Phytplnktn	--	0.015	[illegible]	1.0E-06	6.7E-05	1.0E-02	3.3E-05	0.100	0.100	--	0.100
Invrtebrte	20000	[illegible]	0.002	1.0E-06	1.0E-05	5.0E-04	5.0E-06	0.005	0.005	0.100	0.105
Small fish	--	0.033	0.006	1.0E-06	3.0E-05	1.6E-04	1.5E-05	0.002	0.002	0.105	0.107
Large fish	42000	0.1	0.0015	1.0E-06	1.0E-05	6.7E-04	5.0E-06	0.007	0.007	0.107	0.113
Avian		2000	50.000	1.5E+00	7.5E-04	3.0E-02	3.0E-04	0.300	0.300	0.113	0.414
Criteria-based		0.002	1.4E-05	1.0E-06	0.001	0.071	2.5E-04	0.714			0.715

Table B.19

RISK ANALYSES - ECOLOGICAL

Uncertainty Case 4
Soil Conc 1.000 ppm

	(Reference only) Bioconc Factor	(mg/kg if terrestrial) Acute Tox (LC50) (mg/l)	Chronic Tox (mg/l)	Conc in Media (mg/l)	Relative Acute Risk	Relative Chronic Risk	Percent Acute Reductn	Percent Chronic Reduca	Percent Direct Reduction in Popn Biomass	Percent Indirect Reduction in Popn Biomass	Percent Total Reductn in Popn Biomass
Mink	1.000	6000	0.640	0.010	1.7E-06	1.6E-02	8.3E-07	0.156	0.156	--	0.156
AQUATIC											
Phytplaktn	--	0.015	1.0E-04	1.0E-07	6.7E-06	1.0E-03	3.3E-06	0.010	0.010	--	0.010
Invertebrte	20000	0.100	0.002	1.0E-07	1.0E-06	5.0E-05	5.0E-07	0.001	0.001	0.010	0.011
Small fish	--	0.033	0.006	1.0E-07	3.0E-06	1.6E-05	1.5E-06	0.000	0.000	0.011	0.011
Large fish	42000	0.1	0.0015	1.0E-07	1.0E-06	6.7E-05	5.0E-07	0.001	0.001	0.011	0.011
Avian		2000	50.000	1.5E+00	7.5E-04	3.0E-02	3.0E-04	0.300	0.300	0.011	0.312
Criteria-based		0.002	1.4E-05	1.0E-07	0.000	0.007	2.5E-05	0.071			0.071

Table B.20. COST ANALYSES Uncertainty Case 4

Distance to burn facility 500 miles

Unit Costs

Incineration (liquid)	350.0 $/ton
Incineration (solid)	500.0 $/cu yd
Transportation	0.50 $/cu yd-mile
Excavate & Backfill	100.0 $/cu yd

Interest rate	0.080
Discount Factor	1.059

ALTERNATIVES
(cost values are in million dollars)

Item	Year Cost Realized	OPTION A	OPTION B		
		Incinerate	No Cleanup	Cleanup to 10 ppm	Cleanup to 1 ppm
Quantity of Waste Material		10,000 gal		1666.000 cu yd	3600.000 cu yd
Immediate Destruction		0.030	N/A	N/A	N/A
RI/FS	6		0.423	0.423	0.423
Remediation	8	N/A	N/A		
Excavate & Backfill				0.263	0.569
Transportation				0.658	1.422
Incineration				1.316	2.844
Overhead				0.559	1.209
Contingency				0.224	0.483
Total Remdiatn	8	0.000	0.000	3.020	6.526
Fines	7	0.000	0.100	0.000	0.000
Human Health Litigation	7	0.000	8.587	0.686	0.308
Environmental Litigation	8	0.000	0.071	3.59E-03	3.59E-04
"Benefits" of Invested Capital	5	0.000	0.044	0.044	0.044
Net Present Cost		0.030	6.134	2.641	4.605

Table B.21. COST ANALYSES Uncertainty Case 5

Distance to burn facility 500 miles

Unit Costs

Incineration (liquid)	450.0 $/ton
Incineration (solid)	650.0 $/cu yd
Transportation	1.00 $/cu yd-mile
Excavate & Backfill	125.0 $/cu yd

Interest rate 0.060

Discount Factor 1.029

ALTERNATIVES
(cost values are in million dollars)

Item	Year Cost Realized	OPTION A Incinerate	OPTION B No Cleanup	OPTION B Cleanup to 10 ppm	OPTION B Cleanup to 1 ppm
Quantity of Waste Material		10,000 gal		2500.000 cu yd	5000.000 cu yd
Immediate Destruction		0.048	N/A	N/A	N/A
RI/FS	6		0.356	0.356	0.356
Remediation	8	N/A	N/A		
Excavate & Backfill				0.393	0.786
Transportation				1.573	3.145
Incineration				2.045	4.089
Overhead				1.003	2.005
Contingency				0.401	0.802
Total Remdiatn	8	0.000	0.000	5.414	10.828
Fines	7	0.000	0.100	0.000	0.000
Human Health Litigation	7	0.000	14.073	1.125	0.506
Environmental Litigation	8	0.000	0.009	4.28E-04	4.28E-05
"Benefits" of Invested Capital	5	0.000	0.064	0.064	0.064
Net Present Cost		0.048	11.845	5.469	9.265

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